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METHODS FOR THE DEVELOPMENT OF SHIPBOARD HABITABILITY  
DESIGN CRITERIA - BIBLIOGRAPHY ON HABITABILITY WITH  
ABSTRACTS

CALIFORNIA UNIVERSITY

PREPARED FOR  
OFFICE OF NAVAL RESEARCH

OCTOBER 1973

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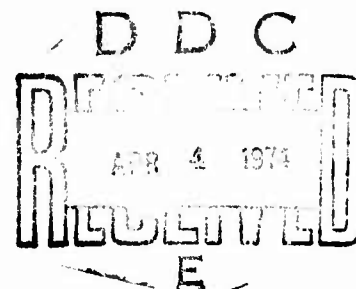
**METHODS FOR THE DEVELOPMENT OF SHIPBOARD  
HABITABILITY DESIGN CRITERIA**

**TECHNICAL REPORT NO. 1  
BIBLIOGRAPHY ON HABITABILITY  
WITH ABSTRACTS**

**SUPPORTED BY  
OFFICE OF NAVAL RESEARCH  
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**SUBMITTED BY  
Sami Hassid, Principal Investigator  
Craig McArt  
Hugo Blasdel, Co-Investigators  
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## INTRODUCTION

This bibliography on habitability was developed over a 17-month period as part of the research effort supported by the Office of Naval Research, Engineering Psychology Programs, Department of the Navy, under Task Order No. 0014-69-A0200-1058.

The bibliography attempts to survey the methodology and results of habitability research, with a particular emphasis on new methods. Research on habitability is essentially multi-disciplinary in nature, with contributions coming from many diverse fields. Relevant material may be gleaned from almost every field of human endeavor, and no single bibliography can be all-inclusive. The areas covered in the following chapters are the result of selections reflecting the particular areas of interest of the investigators, and the immediate needs of the research project on "Methods for the Development of Shipboard Habitability Design Criteria," in the context of which this bibliography was developed. The chapters represent sharply separate areas, with little or no overlap between them. Two chapters have been subdivided into sections in order to accommodate the discrete categories of the research topic.

Abstracts are provided for a large number of entries. Wherever possible, these abstracts are those originally provided in journals. In

numerous cases, abstracts were prepared from summaries or the body of the reports. An effort has been made to reduce less relevant material, to eliminate ambiguity, and to clarify the main thrust of the argument. Care has been taken to avoid violence to the authors' intentions, but the complete argument can best be obtained from the original book or article. The introductory statements in each chapter draw attention to important contributions in the field. The coverage is uneven, reflecting the nature of the disciplines involved.

The work on noise was begun under DOT Contract OS-A9-118, directed by W. W. Soroka, with the participation of Carrol Worster. The other sections were developed specifically for ONR under the task order mentioned above. The three investigators directed the search for and compilation of items, with the assistance of Henry Yu, Robert Hotten, and Vianne Ramirez. Editing was done in part by Patsy Babbitt, and was completed by Linda Brubaker.

Hugo Blasdel produced the work related to scaling, noise, light and thermal responses; Craig McArt prepared the chapters on color and seating; Sami Hassid directed the group effort and more specifically the chapters on perception, modeling, and group interaction. He also prepared the final text for the introductory sections from notes submitted by the other participants.

Phipps Arabie, Ph.D. candidate in psychology, Stanford, was consulted on the multidimensional scaling section. Dr. Martin A. Toltcott, Director, Psychological Sciences Programs, Office of Naval Research, was the scientific officer for this project.

## Chapter I

### MULTIDIMENSIONAL SCALING

There have been several major areas of activity in multidimensional scaling in the past two decades. Recent work started with *Torgerson's*\* assembly of his own and past work into *Theory and Methods of Scaling* (New York, Wiley, 1958) which combined the diverse publications on unidimensional and multidimensional scaling into a single text. Some further work by *Messick and Abelson* on a suggestion by Tucker helped to solve the problem of the additive constant raised in Torgerson's work. That research represented the last major work in two-way metric multidimensional scaling (except for a paper by *Cooper*), and the effort turned toward "non-metric" procedures and later toward "N-way" or multiple-matrix procedures.

The non-metric procedures were developed by *Shepard* and later *Kruskal* at Bell Telephone Laboratories with further work by *Young and Torgerson*. As Cliff indicates, non-metric scaling actually assumes a metric model but does not assume linear ratio scale judgments on the part of participants (*Annual Review of Psychology* Vol.24,

\*Italicized names refer to work in the annotated bibliography. Since often there are several papers by the same author on the same topic, it would be awkward to cite all, or omit any, and the reader is encouraged to address each author's work as a whole.

1973). This non-metric technique became very popular, despite a lack of evidence that the non-linearities in human judgment were of such importance as to compensate for the loss of error reduction (compared to metric techniques), and for the degenerate solutions for a small number of stimuli, to which non-metric techniques are susceptible. It often was difficult for non-theoreticians to interpret their scaling configurations, while keeping within the limitations of dimensionality that are numerically imposed in such an analysis. Shepard discusses this problem at length in the two volume edited work by Shepard, Romney and Nerlove, *Multidimensional Scaling: Theory* (Volume I), and *Applications* (Volume II) (New York, Seminar Press, 1972).

Metric procedures again reemerge in *Carroll and Chang's* work at the Bell Telephone Laboratories. The INDSCAL program they developed solved two pressing problems. Instead of requiring a "rotation of axis" to find a meaningful orientation, the procedure finds a unique set of axes which simultaneously fits the data from several matrices (or several sets of matrices, thus the terminology "N-way"). With the unique orientation, the difficulties of interpretation are less severe and Shepard's objection to solutions of high dimensionality may be satisfied. Carroll and Chang follow *Horan's* approach to combining data so as not to unduly restrict dimensionality or distort the results by some form of averaging. The authors utilize the matrices for each individual's judgments, and derive data on individual differences as a result. Other procedures may be based on this approach which develop matrices for each generator of dissimilarity (often rating scales) and which initially aggregate the data from many individuals (Blasdel, H. G., *Identifying the Perceived Attributes of the Designed Environment Utilizing Multidimensional Scaling* (Berkeley, Department of Architecture, 1973)). Carroll's contribution also includes the development of methods of mapping preference functions on the attributes so that the relative desirability of each pair of stimuli may be determined from the ratings of the stimuli on the attributes.

It is not possible to mention rating scales without due historical reference to the work of Osgood, Suci, and Tannenbaum on the "semantic differential", however unproductive the factor analytic procedure may have been in extracting information from such data (*The Measurement of Meaning* (Urbana, University of Illinois Press, 1957)). *Tucker's* three-mode analysis was initially applied to such data, and has also been applied to multidimensional scaling but it

does not yield unique orientations. The three-mode analysis is a precursor to INDSCAL in handling multiple matrices, as was the work of *Tucker and Messick* (subject to critique by *Ross* and response by *Cliff*), and the work of *Bloxom* and *McGee*.

Although much progress has been made, it is not clear what additional analytic techniques may be possible. INDSCAL has been extended to allow for non-metric analyses, and other non-metric programs are still being developed for greater ease of use and reliability. There is a relatively open field in developing statistical indicators of the adequacy of scaling solutions, although there are also proposed tests for satisfactory solutions (as developed by *Young, Sherman, and Spence* and others on the assumptions described by *Ramsay*). This work has involved Monte Carlo techniques, and little theoretical analysis. Further Monte Carlo studies of INDSCAL with profile data, which do provide tests of each dimension, are given in the companion volume to this bibliography, *Multidimensional Scaling of Real and Simulated Environments*. Recent work of *Krantz, Luce, Suppes and Tversky, Foundations of Measurement* (New York, Academic Press, 1971), is another recent addition to the body of knowledge and also recapitulates previous work by *Beals, Krantz, and Tversky*. While firm foundations are at times necessary, this form of fundamental research has not led to new experimental results, but serves mainly to assure the skeptical "hard" scientist that a rigorous theoretical foundation is available. Monte Carlo studies serve the same end, treating the analysis process as a noise reducing black box which is used to examine a simulation of another black box for systematic output.

The motivation is that in demonstrating the capacity for recovery of simulated data, the application of the analysis technique to human responses may also yield evidence of systematic phenomena. The analysis techniques can only be "tuned" to recover certain kinds of systematic data, and the hope for the future is that analysis techniques will become more powerful through both better recovery and through being tuned to a wider range of phenomena.

## MULTIDIMENSIONAL SCALING

Anderson, A.B. BRIEF REPORT: THE EFFECT OF AGGREGA-  
1970 TION ON NONMETRIC MULTIDIMENSIONAL SCALING  
SOLUTIONS. *Multivariate Behavioral Research* 5(3), 369-73.

A nonmetric multidimensional scaling analysis was done on similarities between twelve objects on data gathered from forty-two subjects. First, each subject's data were used to produce a separate configuration. Then, data were aggregated over all subjects and a single solution configuration was obtained. Comparisons between the two approaches were made. Generally, it was found that aggregation did not produce a configuration which differed greatly from those obtained by analyzing each subject's configuration separately. However, the aggregate stress figures consistently indicated a far better fit than did the corresponding individual stress values.

Arnold, J.B. A MULTIDIMENSIONAL SCALING STUDY OF SE-  
1971 MANTIC DISTANCE. *J. Exper. Psychol.* 90(2), 349-72.

A set of adjectives, a set of nouns, and a set of verbs were each scaled applying Kruskal's multidimensional scaling method to rated dissimilarities in meaning. The same sets of concepts were unidimensionally scaled on qualities closely related to the three most salient semantic differential factors. The clearest finding was that semantic distance associated

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with judgments of dissimilarity is not Euclidian. The evidence strongly suggests that in forming a dissimilarity judgment, differences are suppressed on all dimensions except the one that maximally discriminates the members of a concept pair. The term "maximum component distance" was coined to characterize the apparently best fitting distance model. All three sets of dissimilarities allowed the extraction of at least four dimensions. The noun and adjective dimensions predicted the semantic differential scales rather well, but no semantic differential scale appeared to be collinear with any dissimilarity dimension. In the case of the verbs, only the good-bad semantic differential scale showed significant correlation with the dissimilarity dimensions.

Beals, R., Krantz, D.H. and Tversky, A. FOUNDATIONS OF MULTIDIMENSIONAL SCALING. *Psychol. Review* 75(2), 1968 127-42.

This paper analyzes multidimensional scaling from the standpoint of measurement theory. The qualitative properties that must be satisfied if an ordering of dissimilarities is to be representable by an ordering of distances in any one of a wide variety (Euclidean, etc.) of distance geometries are exhibited and discussed. In the current practice of multidimensional scaling, the representability of stimuli by specific types of distance geometry is rarely questioned. The computational methods in use give a "best" answer, regardless of whether the underlying model is appropriate. In contrast, geometric representations are here regarded as a form of quantitative theory. Those properties of ordinal data that make a given model appropriate, the psychological meaning of those properties, and the structure of critical experiments that test them are studied.

Bechtel, G.G. A DUAL SCALING ANALYSIS FOR PAIRED COMPOSITIONS. *Psychometrika*, 36, 1971a 135-54.

A paired composition is a response upon a dependent variable to the ordered pair  $(j,k)$  of stimuli, treatments, etc. This paper develops an alternative analysis for the paired compositions layout previously treated by Bechtel's [1967] scaling



model. The alternative model relaxes the previous one by including row and column scales that provide an expression of bias for *each* pair of objects. The parameter estimation and hypothesis testing procedures for this model are illustrated by means of a small group analysis, which represents a new approach to pairwise sociometrics and personality assessment.

Bechtel, G.G. A COVARIANCE ANALYSIS OF MULTIPLE  
1971b PAIRED COMPARISONS. *Psychometrika*, 36, 35-55.

In the method of multiple paired comparisons the dominance of object  $j$  over object  $k$  is observed upon  $p$  attributes. The present paper develops a covariance analysis for these paired comparisons in terms of a linear model which includes scale, bias, and interaction effects, along with  $s$  covariates upon which the comparisons are presumably dependent. The covariance model gives rise to adjusted parameter estimates and hypothesis tests for the residual pairwise layout from which the effects of the  $s$  covariates have been removed. These estimation and testing procedures are illustrated with an analysis of political judgment data, and their relevance to the general problem of residual scaling is discussed.

Bechtel, G.G., Tucker, L.R. and Chang, W.C. A SCALAR PRODUCT  
1971 MODEL FOR THE MULTIDIMENSIONAL SCALING OF  
CHOICE. *Psychometrika*, 36, 369-88.

A multidimensional scaling analysis is presented for replicated layouts of pairwise choice responses. In most applications the replicates will represent individuals who respond to all pairs in some set of objects. The replicates and the objects are scaled in a joint space by means of an inner product model which assigns weights to each of the dimensions of the space. Least squares estimates of the replicates' and objects' coordinates, and of unscalability parameters are obtained through a manipulation of the error sum of squares for fitting the model. The solution involves the reduction of a three-way least squares problem to two subproblems, one trivial and the other solvable by classical least squares matrix factorization. The analytic technique is illustrated with political preference

data and is contrasted with multidimensional unfolding in the domain of preferential choice.

**Bloxom, B. INDIVIDUAL DIFFERENCES IN MULTIDIMENSIONAL SCALING. Princeton, N.J.: Educational Testing Service, Research Bulletin 68-45.**

Applications of Tucker and Messick's model of individual differences in multidimensional scaling have suggested the occasional appropriateness of a refinement of that model. The refinement is to consider just one multidimensional stimulus space for all persons (or sets of persons) and with each person having a "weight" for each axis. This paper presents a formal description of this model and a least squares solution for its parameters. The solution has yet to be tested empirically.

**Bradley, J.V. UTILIZATION OF MULTIPLE CUES IN PAIRED COMPARISONS. *Human Factors* 11(4), 361-78.**

Subjects were given one, two, or three cues with which to make an either-or decision. Certain hypotheses were formulated to describe the subject's thought process in utilizing the multiple cues, and mathematical models were constructed to simulate them. The models were then used on data for the single-cue case to predict performance in the multiple-cue case. Predicted performance "data" were then compared with actually observed data for the same multiple-cue case, thus testing the predictive validity of the mathematical model and the tenability of the corresponding hypothesis.

**Bricker, P.D. and Flanagan, J.L. SUBJECTIVE ASSESSMENT OF COMPUTER-SIMULATED TELEPHONE CALLING SIGNALS. *IEEE Trans. Aud. and Electroacoustics*, Au-18(1), 19-25.**

An experimental family of tones intended as telephone calling signals was generated by computer simulation. The synthesis technique allowed systematic manipulation of the parameters of the tones. Selected results of the computations were submitted to listeners for evaluative judgments. The evaluative data were analyzed by a multidimensional method

that reveals the perceptual dimensions on which listeners' opinions differ. The dimensions thus defined were interpreted in terms of the parameters of the synthesis.

Bricker, P.D., Johnson, S.C. and Mattke, C.F. APPARATUS FOR  
1969 AUDITORY STIMULUS SORTING. *Behavioral Research  
Methods and Instruments*. 1(4), 148-49.

Bricker, P.D., Johnson, S.C. and Mattke, C.F. APPARATUS AND  
1968 TECHNIQUE FOR AUDITORY STIMULUS SORTING. *J.  
Acoustic Soc. Amer.*, 44, 388.

Bricker, P.D. and McDermott, B.J. SUBJECTIVE EVALUATIONS  
1970 OF TONE RINGERS BY A SORTING TECHNIQUE. Bell  
Telephone Laboratories, mimeographed house paper.

Carroll, J.D. AN OVERVIEW OF MULTIDIMENSIONAL SCALING  
1970 METHODS EMPHASIZING RECENTLY DEVELOPED  
MODELS FOR HANDLING INDIVIDUAL DIFFERENCES.  
Bell Telephone Laboratories, mimeographed house paper.

Carroll, J.D. POLYNOMIAL FACTOR ANALYSIS. Reprinted from  
1969 the Proceedings of the 77th Annual Convention of the APA.

A number of nonlinear generalizations of factor analysis have been proposed recently. They include McDonald's (1962) approach in which a linear factor structure is rotated to find nonlinear relations (mediated by specific polynomial forms postulated *a priori*), the "local" proximity analysis and the parametric mapping technique described by Shepard and Carroll (1966), and, most recently, the method of nonlinear principal components proposed by Gnanadesikan and Wilk (1969). Polynomial factor analysis (PFA) is closest to McDonald's approach, in that a specific class of polynomial functions is assumed to characterize the relation between "manifest" or observed variables and underlying "latent" variables or factors.

Carroll, J.D. INDIVIDUAL DIFFERENCES AND MULTIDIMEN-  
1970 SIONAL SCALING. Bell Telephone Laboratories, mimeo-  
graphed house paper.

Several approaches are discussed for analysis of individual differences in judgments of similarity and of preference (or other "dominance" judgments). Emphasis is on both theoretical underpinnings and practical data analysis. In the case of similarity judgments special emphasis is placed on a model for individual differences in perception that assumes differential weighting of, or "salience" for, a common set of stimulus dimensions. A method is described for analyzing data in terms of such a model by using a procedure for decomposing three-way (or N-way) tables into a kind of product of three (or N) matrices, each of the same "small" rank. This analysis results in a "group stimulus space" plus a "subject space", in which the subject's weights for the various dimensions are uniquely specified (hopefully obviating the "rotation" problem), parsimony and economy as compared to separate analyses of subjects or groups of subjects, and a potentially useful parameterization of the subjects as well as stimuli. In the case of preference judgments a hierarchy of models is discussed, beginning with the vector model first proposed by Tucker, going on to the unidimensional and multidimensional unfolding, or "ideal point" models of Coombs, Bennett and Hayes, and proceeding to generalizations of the unfolding model involving differential weighting of dimensions and differential rotation of the coordinate axes followed by differential weighting of the rotated dimensions thus defined. The possibility of negative weights is also discussed and its implications as to the nature of "isopreference contours" and the status of the "ideal point" notion. Even more general models are discussed, in which there may be more than a single optimum stimulus value or region. Methods are discussed for both *internal* analysis (based solely on the preference data) and *external* analysis (in which preferences are related to an *a priori* stimulus space derived by multidimensional scaling of similarities data). An interconnected set of methods for external analysis in terms of the hierarchy of models mentioned above is discussed in detail. Collectively, these comprise an approach referred to as "preference mapping of stimulus space". A number of actual and potential methods for internal analysis of preference data are touched on. A new method called polynomial factor analysis is discussed in terms of its particular potential for providing a very general method of

analysis, both of the internal and external varieties, in the preference domain. Several of these methods are brought to bear on an illustrative set of data involving both similarity and preference judgments by a number of subjects on pairs of verbally described hypothetical cups of tea varying in temperature and sweetness.

**Carroll, J.D. and Chang, J.J. ANALYSIS OF INDIVIDUAL DIFFERENCES IN MULTIDIMENSIONAL SCALING VIA AN N-WAY GENERALIZATION OF "ECKHART-YOUNG" DECOMPOSITION.** Bell Telephone Laboratories, mimeographed house paper.

An individual differences model for multidimensional scaling is outlined; individuals are assumed differentially to weight the several dimensions of a common "psychological space". A corresponding method of analyzing similarities data is proposed, involving a generalization of "Eckhart-Young analysis" to decomposition of three-way (or higher way) tables. In the present case, this decomposition is applied to a derived three-way table of scalar products between stimuli for individuals. This analysis yields a stimulus by dimensions coordinate matrix and subjects by dimensions matrix of weights. This method is illustrated with data on auditory stimuli.

**Carroll, J.D. and Chang, J.J. HOW TO USE INDSCAL, A COMPUTER PROGRAM FOR CANONICAL DECOMPOSITION OF N-WAY TABLES AND INDIVIDUAL DIFFERENCES IN MULTIDIMENSIONAL SCALING.** Bell Telephone Laboratories, mimeographed house paper.

**Carroll, J.D. and Chang, J.J. A NEW METHOD FOR DEALING WITH INDIVIDUAL DIFFERENCES IN MULTIDIMENSIONAL SCALING.** Bell Telephone Laboratories, tech. memo.

**Carroll, J.D. and Wish, M. MULTIDIMENSIONAL SCALING OF INDIVIDUAL DIFFERENCES IN PERCEPTION AND JUDGMENT.** Bell Telephone Laboratories, mimeographed house paper.

Cattell, R.B. MULTIVARIATE BEHAVIORAL RESEARCH AND  
1966 THE INTEGRATIVE CHALLENGE. *Multivariate Behavioral  
Research* 1, 4-23.

Often the concepts that form the theoretical stock-in-trade of a certain area are the insufficiently developed and verified products of bivariate research extending over scarcely more than half a dozen of the hundreds of variables really defining the "business" of the domain. Once formed, these improvised, prematurely crystallized concepts are hard to eradicate. A comprehensive, representative array of variables in a domain, such as can be readily covered by multivariate methods, if used at the "outset", effectively guarantees adequate breadth of reference and potency of concept. In several cases, even when the introduction of a more representative design has come quite late, it has been the means of sweeping aside archaic conceptual obstacles. For example, the indication by multivariate analysis of two distinct factor patterns, respectively for anxiety response and stress response, has cleared up some years of difficulty and confusion in interpreting bivariate "anxiety" findings. A whole area can be covered by many years of systematic successive bivariate steps, but, human persistence and cooperation being what they are, this is seldom achieved in practice. Viewed in either logical or statistical terms, a concept can rarely be precisely operationally defined with rigor by a single variable. A concept needs to be tied down by a whole "pattern" of manifestations. Generally, its unity needs to be factorially demonstrated before it is safe even to assume that the theorist's assumption of a "single" conceptual entity can be trusted. Furthermore, we only sharpen our theory about an entity by knowing what is definitely not in it as well as what is in it, and here the richer multivariate approach more readily provides a list of what does not belong. For example, consideration of variates whose vectors determine the hyperplane normal to a factor leads to a clearer definition of the factor itself than does the mere inspection of those variates whose vectors are more nearly collinear with the factor in somewhat the same way that consideration of the (all too) few things "controlled" in a bivariate experiment enhances the interpretation of the observations made of the dependent variable. Thus, most con-

siderations of the philosophy of scientific method and theory building point to an immense advantage, as regards perspective, given by a multivariate experiment.

Cliff, N. THE "IDEALIZED INDIVIDUAL" INTERPRETATION  
1968a OF INDIVIDUAL DIFFERENCES IN MULTIDIMENSIONAL SCALING. *Psychometrika* 33(2), 225-32.

It is shown that several variants of the Tucker-Messick points-of-view procedure are interpretable in terms of their "idealized individual" concepts. It is contended that the main function of the method is that it allows the computation of "several" vectors of mean judgments instead of only one, and that each of these may be used to stand for the actual judgments of a subgroup of subjects. Vectors that do not correspond to the judgments of any subjects are to be avoided. It is alleged that Ross's interpretation of "points-of-view" is quite different from that intended by Tucker and Messick.

Cliff, N. ADJECTIVE CHECK LIST RESPONSES AND INDIVID-  
1968b UAL DIFFERENCES IN PERCEIVED MEANING. *Educational and Psychological Measurement*, 28, 1063-77.

The study is an investigation of the nature of inventory response. Subjects responded to an adjective check list under candid and faking directions and also judged the degree of differentness in meaning of 20 of the adjectives. Eight prototypical answer patterns were derived for the 20 adjectives under the candid set, and the differentness judgments corresponding to each were analyzed by a multidimensional scaling procedure to yield multidimensional meaning spaces. The study concludes (1) that the faking responses and probably also the candid ones were simple functions of the positions of the adjectives in the meaning space; (2) that there was great unanimity among the subjects concerning how to fake; (3) that the differences among individuals' candid responses were not accountable as differences in perceived favorableness and probably not by other differences in perceived meaning, since there was substantial agreement about these too.

Coan, R.W. FACTS, FACTORS AND ARTIFACTS: THE QUEST  
1964 FOR PSYCHOLOGICAL MEANING. *Psychol. Review*,  
71(2), 123-40.

Issues relating to the psychological interpretation of factors are surveyed and possible solutions are suggested. The most basic arguments regarding the reality and interpretability of factors are examined in terms of preferences for different modes of verbal formulation, preferences for different types of theoretical constructs, and confusion regarding the function of constructs. The multiplicity-parsimony issue largely dissolves when examined in the light of the functions of scientific theory, but the relevant concepts of simplicity and unity need more operational analysis. Arguments regarding the causal status stem largely from widespread failure to analyze causal concepts and focus directly on the component issues. The closely related problems of descriptive generality are examined in the light of a modified hierarchical model.

Cooper, L.G. A NEW SOLUTION TO THE ADDITIVE CONSTANT  
1972 PROBLEM IN METRIC MULTIDIMENSIONAL SCALING.  
*Psychometrika*, 37, 311-22.

A new solution to the additive constant problem in metric multidimensional scaling is developed. This solution determines, for a given dimensionality, the additive constant and the resulting stimulus projections on the dimensions of a Euclidean space which minimize the sum of squares of discrepancies between the formal model for metric multidimensional scaling and the original data. A modification of Fletcher-Powell style functional iteration is used to compute solutions. A scale free index of the goodness of fit is developed to aid in selecting solutions of adequate dimensionality from multiple candidates.

Davidson, J.A. A GEOMETRICAL ANALYSIS OF THE UNFOLD-  
1972 ING MODEL: NONDEGENERATE SOLUTIONS. *Psycho-  
metrika*, 37, 193-216.

Given the complete set  $R$  of rank orders derived from some configuration of  $n$  stimulus points in  $r$  dimensions in accord-



ance with the unfolding model, a stimulus configuration which generates just these orders will be described as a solution for  $R$ . The space is assumed to be Euclidean. Necessary and sufficient conditions are determined for a nondegenerate configuration to be a solution for  $R$ . The geometrical conditions which are necessary and sufficient to determine the subset of pairs of opposite orders are also identified and constitute the constraint system for the ordinal vector model.

Degerman, D. MULTIDIMENSIONAL ANALYSIS OF COMPLEX  
1970 STRUCTURE: MIXTURES OF CLASS AND QUANTITATIVE VARIATION. *Psychometrika*, 35, 475-91.

For certain kinds of structure consisting of quantitative dimensions superimposed on a discrete class structure, spatial representations can be viewed as being composed of two subspaces, the first of which reveals the discrete classes as isolated clusters and the second of which contains variations along the quantitative attributes. A numerical method is presented for rotating a multi-dimensional configuration or factor solution so that the first few axes span the space of classes and the remaining axes span the space of quantitative variation. The use of this method is then illustrated in the analysis of some experimental data.

Eisler, H. MEASUREMENT OF PERCEIVED ACOUSTIC QUALITY  
1966 OF SOUND-REPRODUCING SYSTEMS BY MEANS OF FACTOR ANALYSIS. *J. Acoustic Soc. Amer.*, 39(3), 484-92.

The factor analytic model as here applied conceives of a numerical quality judgment of a certain program played by a given reproducing device as a weighted sum of a measure of the quality of the different reproducing properties (e.g., purity of transients, full treble) possessed by the device in question. The weights constitute measures of the requirements made by the particular program on these properties. Factor analysis splits a raw-data matrix—consisting of quality judgments for a number of combinations of program-loudspeaker systems—into two matrices: a factor-loading matrix consisting of the weights and a factor-score matrix consisting of the

quality of reproducing properties. The rank of these matrices (number of factors) reflects the number of dimensions (properties) that implicitly enter into the listener's judgments. Four listeners judged, on a 7-point scale, the quality of 24 programs (music, speech, traffic noise, etc.) played on ten sound reproducing systems of highly different general quality. The data were factor-analyzed (component analysis of covariances), and factor loadings for the programs and factor scores for the loudspeaker systems were computed. Nine factors were extracted and rotated, and seven of them tentatively interpreted (sound level, purity of transients, high-treble relative midrange, environmental information, bass boost, full-treble reproduction, and disturbing directional effects). An attempt at validation showed good agreement between factor scores (reproducing properties) for the four listeners, in spite of variation of preferences between listeners reflected in factor loadings. Despite technical imperfections, it is concluded that factor analysis is a useful instrument for the assessment of acoustical properties.

**Ekman, G. TWO METHODS FOR THE ANALYSIS OF PERCEPTUAL DIMENSIONALITY.** *Perceptual and Motor Skills*, 20, 1965 557-72.

Two methods for the analysis of a multidimensional subjective variation were described: (1) a direct multidimensional ratio scaling method previously developed by the author and (2) a revised method of similarity analysis that is derived in the present paper from recent investigations of the mechanism involved in similarity judgment. Both methods were applied to data from four experiments covering a variety of perceptual and judgmental areas. It was demonstrated (a) that the results of both methods were in very close agreement, and (b) that these results were simple and easily interpretable.

**Ekman, G. A DIRECT METHOD FOR MULTIDIMENSIONAL RATIO SCALING.** *Psychometrika*, 28(1), 1963 33-41.

A generalization of direct ratio scaling methods to multidimensional ratio scaling is described. This method requires

an observer to report the proportion of a standard percept that is contained in a given percept and vice versa. The method was developed to meet requirements for experimentation in such areas as color vision, gustation, and olfaction.

Ekman, G. DIMENSIONS OF COLOR VISION. *J. Psychol.*, 38, 1954 467-74.

Evans, G.T. TRANSFORMATION OF FACTOR MATRICES TO  
1971 ACHIEVE CONGRUENCE. *Br. J. math. Statist. Psychol.*, 24,  
22-48.

The several problems which are included under the study of factorial similarity are discussed, and the available analytical techniques for rotation to congruence are classified. A new method for the transformation of two or more factor matrices to achieve maximum similarity between them is proposed. The possibility of postulating the same factor structure in different populations and comparing the means, variances, and intercorrelations of factor scores from the different populations is also discussed.

Fenker, R.M., Jr. and Brown, D.R. PATTERN PERCEPTION, CON-  
1969CEPTUAL SPACES, AND DIMENSIONAL LIMITATIONS  
IN INFORMATION PROCESSING. *Multivariate Behavioral  
Research* 4(3) 257-71.

A conceptual space was defined as the collection of all linearly independent psychological dimensions underlying the multidimensional scaling of a set of tasks. When a single subject scaled a sample of random polygons under fifteen different task conditions, a total of ten linearly independent dimensions was obtained. The number of obtained dimensions in individual tasks ranged between 1 and 3. The results suggest the existence of a dimensional limitation upon information processing in MDS studies.

Fischer, W. and Micko, H.C. MORE ABOUT METRICS OF SUBJECTIVE SPACES AND ATTENTION DISTRIBUTIONS. *J. math. Psychol.* 9(1), 36-64.

A new representation of metrics is presented, competing theories of similarity and their geometric representations are compared, and metrics resulting from averaging individual distances are discussed.

**Fleiss, J.L. and Zubin, J. ON THE METHODS AND THEORY OF  
1969 CLUSTERING. *Multivariate Behavioral Research* 4(2),  
235-50.**

The need for methods of clustering individuals into homogeneous groups seems clear. One hopes, by applying them to his data, to discover clusterings which may prove to be important. This aim appears straightforward, but the methods which exist do not necessarily satisfy them. The procedures which employ the correlation measure of profile similarity, and those which employ the distance measure are discussed. Technical and logical problems are shown to exist for both measures. The key defect in almost all clustering procedures seems to be the absence of a statistical model. The suggestion is made that the clustering problem be stated as a mixture problem. The need for further work by psychologists and statisticians is pointed out.

**Garner, W.R. and Felfoldy, G.L. INTEGRALITY OF STIMULUS  
1970 DIMENSIONS IN VARIOUS TYPES OF INFORMATION  
PROCESSING. *Cognitive Psychology*, 1, 225-41.**

Seven experiments were run in which speed of sorting decks of stimulus cards was measured. Stimuli were constructed from two dichotomous dimensions, used either alone, correlated, or orthogonally. Sorting was always into two categories defined by the levels of one dimension. The experiments differed in the nature of the stimulus dimensions. Value and chroma of single Munsell chips and the horizontal and vertical positions of a dot gave results which show facilitation with correlated stimulus dimensions and interference with orthogonal dimensions. Such dimensions, which also produce a Euclidean metric in direct stimulus scaling, are termed *integral*. Value and chroma of separate Munsell chips, as well as size of circle and angle of diameter, gave results which show little or no facilitation or interference. Such

dimensions, which also produce a city-block metric in direct stimulus scaling, are termed *nonintegral*.

Gnanadesikan, R. and Wilk, M.B. DATA ANALYTIC METHODS IN  
1969 MULTIVARIATE STATISTICAL ANALYSIS. In P.R. Krishnaiah, *Multivariate Analysis II*. New York: Academic Press, 593-638.

This paper concerns multivariate statistical techniques, concepts, and data-based interpretations relevant to five general objectives in the analysis of multiresponse data: (1) reduction of dimensionality; (2) development and study of multivariate relationships; (3) multidimensional classification; (4) assessment of statistical models; and (5) summarization and exposure. The coverage includes a review of some relevant published work and also of some new procedures. Specifically, the new statistical methods discussed are: a generalization of linear principal components analysis for detecting and describing nonlinear relations among the responses; the use of regression procedures for multidimensional classification when there are certain systematic variations (due perhaps to experimental artifacts) among the known replicate observations of each category or group; and a technique of multivariate observations for purposes of intercomparing the marginal distributions of the components. Illustrative examples of use of the techniques are given.

Green, B.J., Jr. THE COMPUTER REVOLUTION IN PSYCHO-  
1966 METRICS. *Psychometrika*, 31, 437-44.

The authors postulate that the psychometric methods involving algorithms are completely objective—if the algorithm is in the form of a program for a digital computer. These objective procedures need Monte Carlo and other computer runs to determine their properties, but so do many equation-oriented techniques. The objective algorithms are flexible but not flaccid. They offer a way of dealing with complexities that formerly seemed beyond our grasp. As the computer revolution continues in psychometrics, we can expect objective algorithmic methods to become the rule rather than the exception.

**Green, P.E. and Carmone, F.J. THE EFFECT OF TASK ON INTRA-  
1972 INDIVIDUAL DIFFERENCES IN SIMILARITIES JUDG-  
MENTS. *Multivariate Behavioral Research*, 6(4), 433-50.**

In a recent MBR article (1969), Fenker and Brown discuss the relationship between task spaces and conceptual space in the multidimensional scaling of similarities judgments. This article extends some of their research to the case of multiple judges and real stimuli—a set of twenty bakery type food items. In addition, the relationship between overall similarities judgments and task-specified similarities judgments is examined. The results of this experiment tend to support the earlier findings of Fenker and Brown that the scaling of task-dependent similarities judgments taps only a subset of the dimensions of conceptual space. Moreover, the scaling of overall similarities (task unspecified) does not predict the approximated conceptual space with high accuracy. The authors discuss a number of techniques, including Carroll's and Chang's INDSCAL procedure (1970) for finding conceptual space approximations.

**Green, P.E. and Carmone, F.J. MULTIDIMENSIONAL SCALING:  
1969 AN INTRODUCTION AND COMPARISON OF NONMET-  
RIC UNFOLDING TECHNIQUES. *J. Marketing Research*, 6,  
330-41.**

This article first describes some of the basic concepts of multidimensional scaling of similarities and preference data and provides a short description of its historical development. Then it reports an empirical comparison of three computer programs for unfolding preference data to "recover" a stimulus configuration (independently obtained). Results indicate differences among the resulting configurations that reflect the influence of differential weighting of "perceptual" dimensions in the context of preference.

**Green, P.E., Maheshwari, A. and Rao, V.R. DIMENSIONAL INTER-  
1969 PRETATION AND CONFIGURATION INVARIANCE IN  
MULTIDIEMNSIONAL SCALING: AN EMPIRICAL  
STUDY. *Multivariate Behavioral Research*, 4(2), 159-80.**

This paper is concerned with: (a) the invariance of nonmetric multidimensional scaling solutions over changes in stimulus domain; and (b) procedures for assisting the researcher in interpreting the axes of multidimensional scaling configurations. The stimuli consisted of the names of seventeen popular brands of automobiles. Similarities and preference judgments were obtained from thirty-seven subjects, divided into two groups of approximately equal size. Each group received eleven of the seventeen stimuli. A core set of five stimuli was common over both groups. Each group also rated the eleven car models on twenty semantic differential scales. Results of the study suggested that the interpoint distances of the core set of five stimuli remained stable over subject groups and differences in stimulus set composition. Semantic differential ratings were used to find directions in the configural space (obtained from overall similarity judgments) whose projections were maximally correlated with the "outside" (property) vectors. Stimulus configurations developed from the semantic differential "space" were highly congruent with those found by analysis of direct similarity judgments. However, attempts to develop stimulus configurations by the "unfolding" of preference data alone did not lead to configurations which closely matched those found by analysis of direct similarities data.

Green, P.E. and Rao, V.R. A NOTE ON PROXIMITY MEASURES  
1969 AND CLUSTER ANALYSIS. *J. Marketing Research*, 6,  
359-64.

This paper compares, theoretically and empirically, ten types of proximity measures advocated by various researchers interested in clustering and related techniques. A common (miniature) data bank and clustering routine was used. As seen, the clustering algorithm was sensitive to type of proximity measure used, and different cluster compositions resulted. Apparently, in this example, proximity measures based on a preliminary *Q*-type analysis of the intermodel correlation matrix and Kendall's nonparametric method produced the most disparate cluster compositions compared with the other methods. Finally, the authors propose an adaptation of Johnson's procedure (originally developed for studying individual

differences among subjects' subjective clustering of a group of stimuli) as a way to characterize spatially results of clustering based on various proximity measures. They speculate that this graphical approach may also be useful descriptively in portraying similarities among different clustering algorithms. The need for such comparisons seems particularly acute in view of the increasing number of clustering programs being proposed and the lack of a firm analytical base for evaluating their similarities and differences in applications to real data.

**Gregson, R.A.M. ODOUR SIMILARITIES AND THEIR MULTIDIMENSIONAL METRIC REPRESENTATION. *Multivariate Behavioral Research*, 7, 165-74.**

Odour qualitative similarities were collected on 18 subjects, using 10 diverse stimuli. Responses were in numerical category scale form, and were analyzed individually and pooled by a nonmetric multidimensional scaling program, TORSCA. It is suggested that the data are consistent with a degenerate metric space configuration here called a "reflected simplex." Implications for psychophysical odour quality typologies are noted.

**Gregson, R.A.M. THEORETICAL AND EMPIRICAL MULTIDIMENSIONAL SCALINGS OF TASTE MIXTURE MATCHINGS. *Brit. J. math. statist. Psychol.*, 19, 59-76.**

Kruskal's nonmetric method was used to provide a multidimensional scaling of two experiments in which a series of taste mixtures with three and four chemical components each were matched to histogram pictures of taste mixtures. The results yielded dimensions of a space which could be related to the chemical composition of the stimuli: suggestions are made for reformulating the distance metric to take account of psychophysical response processes known to underlie taste comparisons. Scaling problems which arise as a consequence of the limitations of taste as a conveyor of sensory information are noted; possible methods of multidimensional scaling by matching theoretical and empirical interstimulus distances are discussed.



Gregson, R.A.M. and Russell, R.N. A NOTE ON A GENERATING  
1967 ASSUMPTION IN McGEE'S MULTIDIMENSIONAL ANAL-  
YSIS OF 'ELASTIC' DISTANCES. *J. math. statist. Psychol.*,  
20(2), 239-42.

Evidence is offered that multidimensional similarity judg-  
ments do not behave in a way demanded for an elastic dis-  
tance model advanced by McGee. Problems concerning the  
properties of similarity data which can be included in scaling  
models are indicated.

Gulliksen, H. MATHEMATICAL SOLUTIONS FOR PSYCHOLOGI-  
1959 CAL PROBLEMS. *Amer. Scientist*, 47, 178-201.

An attempt has been made to show the value of the mathe-  
matico-deductive approach to various psychological prob-  
lems, and in particular to indicate the very general applica-  
bility of two techniques: (1) The usefulness of matrix algebra  
for expressing a large number of psychological theories and  
for comparing the theory (observation equations) with data;  
(2) the generality of multidimensional scaling as an approach  
to a variety of psychological problems. In each case the close  
tie between the mathematical statement and the psychologi-  
cal statement has been stressed. For every variation in  
psychological assumptions there must be a matching variation  
in the mathematical equations. When psychological theories  
are translated into mathematical equations, the mathema-  
tician can give the psychologist powerful tools for deriving  
the implications of his assumptions and for testing their cor-  
respondence with data.

Guttman, L. A GENERAL NONMETRIC TECHNIQUE FOR FIND-  
1968 ING THE SMALLEST COORDINATE SPACE FOR A CON-  
FIGURATION OF POINTS. *Psychometrika*, 33.

Let  $A_1, A_2, \dots, A_n$  be any  $n$  objects, such as variables, cate-  
gories, people, social groups, ideas, physical objects, or any  
other. The empirical data to be analyzed are coefficients of  
similarity or distance within pairs  $(A_i, A_j)$ , such as correla-  
tion coefficients, conditional probabilities or likelihoods,  
psychological choice or confusion, etc. It is desired to repre-

sent these data parsimoniously in a coordinate space, by calculating  $m$  coordinates  $\{x_{ia}\}$  for each  $A_i$  for a semi-metric  $d$  of preassigned form  $d_{ij}=d(|x_{i1}-x_{j1}|, |x_{i2}-x_{j2}|, \dots, |x_{im}-x_{jm}|)$ . The dimensionality  $m$  is sought to be as small as possible, yet satisfy the monotonicity condition that  $d_{ij} < d_{kl}$  whenever the observed data indicate that  $A_i$  is "closer" to  $A_j$  than  $A_k$  is to  $A_l$ . Minkowski and Euclidean spaces are special metric examples of  $d$ . A general coefficient of monotonicity  $\mu$  is defined, whose maximization is equivalent to optimal satisfaction of the monotonicity condition, and which allows various options both for treatment of ties and for weighting error-of-fit. A general rationale for algorithm construction is derived for maximizing  $\mu$  by gradient-guided iterations; this provides a unified mathematical solution to the basic operational problems of norming the gradient to assure proper convergence, of trading between speed and robustness against undesired stationary values, and of a rational first approximation. Distinction is made between single-phase (quadratic) and two-phase (bilinear) strategies for algorithm construction, and between "hard-squeeze" and "soft-squeeze" tactics within these strategies. Special reference is made to the rank-image and related transformational principles, as executed by current Guttman-Lingoes families of computer programs.

Helm, C. and Tucker, L.R. INDIVIDUAL DIFFERENCES IN THE  
1962 STRUCTURE OF PERCEPTION. *Amer. J. Psychol.*, 75,  
437-44.

Holman, E.W. THE RELATION BETWEEN HIERARCHICAL AND  
1972 EUCLIDEAN MODELS FOR PSYCHOLOGICAL DIS-  
TANCES. *Psychometrika*, 37, 417-23.

In one well-known model for psychological distances, objects such as stimuli are placed in a hierarchy of clusters like a phylogenetic tree; in another common model, objects are represented as points in a multidimensional Euclidean space. These models are shown theoretically to be mutually exclusive and exhaustive in the following sense. The distances among a set of  $n$  objects will be strictly monotonically related either to the distances in a hierarchical clustering sys-

tem, or else to the distances in a Euclidean space of less than  $n - 1$  dimensions, but not to both. Consequently, a lower bound on the number of Euclidean dimensions necessary to represent a set of objects is one less than the size of the largest subset of objects whose distances satisfy the ultrametric inequality, which characterizes the hierarchical model.

**Horan, C.B. MULTIDIMENSIONAL SCALING: COMBINING OBSERVATIONS WHEN INDIVIDUALS HAVE DIFFERENT PERCEPTUAL STRUCTURES. *Psychometrika*, 34, 139-65.**

The usual methods of combining observations to give inter-point distance estimates based on interstimulus differences are shown to lead to a distortion of the stimulus configuration unless all individuals in a group perceive the stimuli in perceptual spaces which are essentially the same. The nature of the expected distortion is shown, and a method of combining individual distance estimates which produces only a linear deformation of the stimulus is given.

**Jackson, D.N., Messick, S.J. and Solley, C.M. A MULTIDIMENSIONAL SCALING APPROACH TO THE PERCEPTION OF PERSONALITY. *J. of Psychol.* 44, 311-18.**

This experiment was designed to investigate the relevance and appropriateness of multidimensional scaling for studying the perception of personality. This technique avoids the necessity of predetermining the number and the nature of the relevant dimensions. Since the categories used by ordinary people in defining personality are largely unknown, it was thought that the application of this method would be useful as an exploratory device. Twenty subjects, all well acquainted, were assigned the task of judging similarity in personality between all possible pairs of the subjects along a nine-point scale. These distance judgments were subjected to the analytic procedures of multidimensional scaling and resulted in a structure of points corresponding to people in an Euclidean space. Four dimensions were extracted, three of which accounted for a major portion of the variance. These three dimensions were identified tentatively as "theoretical-intellectual," "friendship," and "age-status" by their partial correspon-

dence with data from a personality inventory, friendship ratings, intelligence test scores and age.

Johnson, D.E. THE OFFICE ENVIRONMENT PEOPLE PREFER.  
1970 *AIA Journal*, 56-58.

Johnson, R.M. PAIRWISE NONMETRIC MULTIDIMENSIONAL  
1973 SCALING. *Psychometrika*, 38, 11-18.

A method of nonmetric multidimensional scaling is described which minimizes pairwise departures from monotonicity. The procedure is relatively simple, both conceptually and computationally. Experience to date suggests that it produces solutions comparable to those of other methods.

Keats, J.S. A METHOD OF TREATING INDIVIDUAL DIFFER-  
1964 ENCES IN MULTIDIMENSIONAL SCALING. *Brit. J. statist. Psychol.*, 17, 37-50.

Three studies are reported in which results obtained by analysis using the multidimensional 'unfolding' method are compared with those obtained by multidimensional scaling. Attitudes of undergraduates towards crime, political parties and types of accommodation were assessed by presenting the stimuli two at a time and asking subjects to indicate preferences, as well as rate the differences between each pair of stimuli. Subjects were also asked to indicate whether they liked, disliked or felt indifferent towards each of the stimuli. Samples of approximately 200, 500 and 1,000 subjects respectively were used in the three studies. Where the individual differences in attitudes were relatively small, as in the crimes data, the two methods gave equally adequate representations of the data. However, in their attitudes towards political parties the students showed large individual differences, and this was reflected in considerable disparity between the results obtained by the two methods. An attempt was made to combine the two methods to investigate distortion produced by strong negative attitudes, and the results obtained were linked to a theory of psychological balance. This theoretical explanation seemed appropriate to the results obtained from the study of students' reactions to different types of accommodation.

Kempthorne, O. MULTIVARIATE RESPONSES IN COMPARATIVE EXPERIMENTS. In P.R. Krishnaiah, *Multivariate Analysis*, New York: Academic Press, 521-40.

Kitamura, O., Namba, S. and Matsumoto, R. FACTOR ANALYTICAL RESEARCH OF TONE COLOR. Sixth International Congress on Acoustics, paper A-5-11, A-117-20.

The expression, "tone color," used in this paper, does not only mean the peculiarity of sound, but it also means the whole tonal experience when we hear a sound. In other words, the tone color means the impression which is made from the pattern of pitch and loudness in the total sensation of tone heard. As many descriptive adjectives of tone color as possible were collected from a number of books and magazines of music and acoustics, and from acoustical engineers, musicians and the general populace. The sound stimuli were selected from music, noise and the human voice. The music and noise were selected from records and the human voice was selected from readings by radio announcers.

Klahr, D. A MONTE CARLO INVESTIGATION OF THE STATISTICAL SIGNIFICANCE OF KRUSKAL'S NONMETRIC SCALING PROCEDURE. *Psychometrika*, 34(2), 319-30.

Recent advances in computer based psychometric techniques have yielded a collection of powerful tools for analyzing non-metric data. These tools, although particularly well suited to the behavioral sciences, have several potential pitfalls. Among other things, there is no statistical test for evaluating the significance of the results. This paper provides estimates of the statistical significance of results yielded by Kruskal's non-metric multidimensional scaling. The estimates, obtained from attempts to scale many randomly generated sets of data, reveal the relative frequency with which apparent structure is erroneously found in unstructured data. For a small number of points (i.e., six or seven) it is very likely that a good fit will be obtained in two or more dimensions when in fact the data are generated by a random process. The estimates presented here can be used as a bench mark against

which to evaluate the significance of the results obtained from empirically based nonmetric multidimensional scaling.

Klemmer, E.T. and Shrimpton, N.W. PREFERENCE SCALING VIA  
1963 A MODIFICATION OF SHEPARD'S PROXIMITY ANALYSIS METHOD. *Human Factors*, 5(2), 163-68.

Krantz, D.A. RATIONAL DISTANCE FUNCTIONS FOR MULTIDI-  
1967 MENSIONAL SCALING. *J. Math. Psychol.*, 4, 226-45.

A rational distance function is a numerical measure of psychological distance whose geometric properties are deducible from psychological truths about some particular judgmental task. In this paper, we review two theoretical analyses that have led to proposed rational distance functions. These analyses are based on two different tasks: paired-associate learning and similarity judgments. A generalization of the theory on similarity judgments is presented. Empirical results concerning similarity judgments seriously conflict with the basic psychological assumptions in the generalized treatment of similarity judgments. We conclude from these results that the construction of valid psychologically based distance functions from analysis of choice probabilities in similarity judgments requires, as an initial step, the development of scaling models that take into account the influence of "irrelevant" dimensions on choice probability.

Krantz, D.H. and Tversky, A. CONJOINT-MEASUREMENT ANAL-  
1971 YSIS OF COMPOSITION RULES IN PSYCHOLOGY. *Psychol. Review*, 78, 151-69.

Composition rules are theories that describe the relationships among several measurable variables. Conjoint measurement provides methods for analyzing such rules using ordinal information only. This analysis is applied to a class of four composition rules in three variables [ $A + P + U$ ,  $(A + P)U$ ,  $AP + U$ ,  $APU$ ], which have been widely employed in different areas of psychology. It leads to the formulation of observable ordinal properties that can be used to test and diagnose which of the rules, if any, is appropriate for a given set of data.

Kruskal, J.B. MONOTONE REGRESSION: CONTINUITY AND  
1971 DIFFERENTIABILITY PROPERTIES. *Psychometrika*, 36,  
57-62.

Least-squares monotone regression has received considerable discussion and use. Consider the residual sum of squares  $Q$  obtained from the least-squares monotone regression of  $y_i$  on  $x_i$ . Treating  $Q$  as a function of the  $y_i$ , the author proves that the gradient  $\text{Grad } Q$  exists and is continuous everywhere, and is given by a simple formula. (He also discusses the gradient of  $d = Q^{1/2}$ .) These facts, which can be questioned, are important for the iterative numerical solution of models, such as some kinds of multidimensional scaling, in which monotone regression occurs as a subsidiary element, so that the  $y_i$  and hence indirectly  $Q$  are functions of other variables.

Kruskal, J.B. MULTIDIMENSIONAL SCALING BY OPTIMIZING  
1964a GOODNESS-OF-FIT TO A NONMETRIC HYPOTHESIS.  
*Psychometrika*, 29(1), 1-27.

Multidimensional scaling is the problem of representing  $n$  objects geometrically by  $n$  points, so that the interpoint distances correspond in some sense to experimental dissimilarities between objects. In just what sense distances and dissimilarities should correspond has been left rather vague in most approaches, thus leaving these approaches logically incomplete. Our fundamental hypothesis is that dissimilarities and distances are monotonically related. We define a quantitative, intuitively satisfying measure of goodness-of-fit to this hypothesis. Our technique of multidimensional scaling is to compute that configuration of points which optimizes the goodness-of-fit. A practical computer program for doing the calculations is described in a companion paper.

Kruskal, J.B. NONMETRIC MULTIDIMENSIONAL SCALING: A  
1964b NUMERICAL METHOD. *Psychometrika*, 29(2), 115-29

The author describes the numerical methods required in his approach to multidimensional scaling. The rationale of this approach has appeared previously.

Kruskal, J.B. and Carroll, J.D. GEOMETRICAL MODELS AND  
1969 BADNESS-OF-FIT FUNCTIONS. Reprinted from *Multivariate Analysis-II*, New York: Academic Press, 639-71.

Geometrical models are models such as tree structure, parametric mapping, multidimensional scaling, multidimensional unfolding, and factor analysis. Four of these models are discussed in this paper. For each a brief description is given as well as a brief discussion of its demonstrated utility. One good way to do model fitting is through badness-of-fit or goodness-of-fit functions. The model allows for data values and for parameter values. A badness-of-fit or a goodness-of-fit function is devised which measures or evaluates how well the parameter values in question match the data values being considered. By definition, the best fitting parameter values are those which optimize this function. The central question in this approach is how to choose the badness-of-fit or goodness-of-fit function. This is the problem on which attention is focused here. Our approach is not theoretical, but rather through illustration. For each of the geometrical models we discuss, we describe at least one and sometimes several alternative functions that can be or have been used, and discuss advantages and disadvantages.

Kuennapas, T. ACOUSTIC PERCEPTION AND ACOUSTIC MEMO-  
1968 RY OF LETTERS: MULTIDIMENSIONAL RATIO SCALING AND MULTIDIMENSIONAL SIMILARITY. *Acta Psychologica*, 28, 161-70.

The similarities in acoustic perception and acoustic memory, respectively, of nine letters of the alphabet were studied by direct multidimensional ratio scaling and by the method of multidimensional similarity analysis. Three factors were found which were exactly the same in respect to both perception and memory of these letters, and with nearly identical loadings.

Lingoes, J.C. SOME BOUNDARY CONDITIONS FOR A MONO-  
1971 TONE ANALYSIS OF SYMMETRIC MATRICES. *Psychometrika*, 36, 195-203.



This paper gives a rigorous and greatly simplified proof of Guttman's theorem for the least upper-bound dimensionality of arbitrary real symmetric matrices  $S$ , where the points embedded in a real Euclidean space subtend distances which are strictly monotone with the off-diagonal elements of  $S$ . A comparable and more easily proven theorem for the vector model is also introduced. At most  $n-2$  dimensions are required to reproduce the order information for both the distance and vector models, and this is true for any choice of real indices, whether they define a metric space or not. If ties exist in the matrices to be analyzed, then greatest lower bounds are specifiable when degenerate solutions are to be avoided. These theorems have relevance to current developments in nonmetric techniques for the monotone analysis of data matrices.

**Lingoes, J.C. THE MULTIVARIATE ANALYSIS OF QUALITATIVE DATA. 1968a** *Multivariate Behavioral Research* 3(1), 61-94.

Three methods for analyzing qualitative data are introduced: 1) Multivariate Analysis of Contingencies-II [MAC-II] (based on the early work of Guttman, 1941), 2) Multidimensional Scalogram Analysis-I [MSA-I] (involving a unique definition of contiguity which presupposes minimum assumptions), and 3) Multidimensional Scalogram Analysis-II [MSA-II] (involving graph theoretic and smallest space logic). An outline of the basic equations and assumptions of each are presented. One example of a conceptual data matrix is analyzed by both MSA-I and MSA-II and the results are discussed vis-a-vis a hand analysis by Guttman, imposing parallel straight line boundaries preserving ordered categories. Finally, some comparisons are made between the two scalogram procedures.

**Lingoes, J.C. THE RATIONALE OF THE GUTTMAN-LINGOES NONMETRIC SERIES: A LETTER TO DOCTOR PHILIP RUNKEL. 1968b** *Multivariate Behavioral Research* 3(4), 495-507.

**Lingoes, J.C. AN IBM 7090 PROGRAM FOR GUTTMAN-LINGOES SMALLEST SPACE ANALYSIS, III. 1966** *Behavioral Science*, 11, 75-76.

Lingoes, J.C. RECENT COMPUTATIONAL ADVANCES IN NON-METRIC METHODOLOGY FOR THE BEHAVIORAL SCIENCES. Proc. Intl. Symposium—Mathematical and Computational Methods in Social Science, Rome, International Computation Center, 314.

Lund, T. MULTIDIMENSIONAL SCALING OF GEOMETRICAL FIGURES. *Scand. J. Psychol.* 2(4), 246-54.

In two experiments with geometrical figures as stimuli, constructed in order to generate perceptual variation of roundness and height, four multidimensional scaling methods were compared, two metric and two nonmetric. The methods gave similar solutions. The fact that the solutions could be interpreted in accordance with expectations points to the validity of the methods.

McDermott, B.J. MULTIDIMENSIONAL ANALYSES OF CIRCUIT 1968 QUALITY JUDGMENTS. *J. Acoustic Soc. Amer.*, 45(3) 774-81.

Listeners judged paired comparisons of speech samples transmitted through twenty-two circuits, each of which introduced a different type of distortion. One group of listeners made preference judgments and another group made similarity judgments. A different multidimensional scaling procedure was applied to each set of data. Both of these procedures represent the stimuli as points in a multidimensional subjective space whose coordinates correspond to the subjective attributes underlying the judgments. The procedure applied to the preference judgments also represents the listeners as vectors in the same subjective space. A listener's vector is located according to the relative weight he assigns to each attribute. The results of these analyses revealed a high degree of the correspondence between the three-dimensional solutions representing each type of judgment. The underlying attributes common to the two spaces are interpreted as overall clarity, a distinction between signal distortion and background distortion, and subjective loudness. Listeners generally agree in their preferences for signals according to overall clarity. Individual differences in preference for either signal

or background distortion account for most of the variability between listeners. Some additional variability is introduced by individual differences in preferred loudness.

McDonald, R.P. NONLINEAR FACTOR ANALYSIS. Psychometric  
1967 Monograph 5.

McGee, V.E. A REPLY TO SOME CRITICISMS OF ELASTIC MUL-  
1967 TIDIMENSIONAL SCALING. *J. math. and stat. Psychol.*  
20(2), 243-47.

McGee, V.E. MULTIDIMENSIONAL SCALING OF  $N$  SETS OF  
1968 SIMILARITY MEASURES: A NONMETRIC INDIVIDUAL  
DIFFERENCES APPROACH. *Multivariate Behavioral Re-*  
*search*, 3, 233-48.

Given  $N$  sets of similarity measures between pairs of stimulus objects, a nonmetric multidimensional scaling procedure (known as CEMD) is proposed; the procedure allows one of four kinds of analysis to be performed on the data. The four types of solution are defined in terms of two binary decisions: (a) whether only one configuration is allowed for all  $N$  sets or whether each set is allowed to have its own configuration, and (b) whether the same monotonic transformation is applied to all  $N$  sets of input data or whether each set is allowed its own monotonic transformation. Where separate configurations are allowed, the computer program seeks to keep these solutions as similar as possible and provides an index of the similarity of the configurations.

McGee, V.E. THE MULTIDIMENSIONAL ANALYSIS OF "ELAS-  
1966 TIC" DISTANCES. *Brit. J. math. stat. Psychol.*, 19, 181-96.

Messick, S.J. and Abelson, R.P. THE ADDITIVE CONSTANT  
1956 PROBLEM IN MULTIDIMENSIONAL SCALING. *Psycho-*  
*metrika*, 21, 1-17.

The problem of choosing the correct additive constant to convert relative interstimulus distances to absolute interstimulus distances in multidimensional scaling is investigated. An artificial numerical example is constructed, and various

trial values of the constant are inserted to demonstrate the effect on the multidimensional map of making a variety of incorrect choices. Finally, a general solution to the problem, suggested by Dr. Ledyard R. Tucker, is presented; each of the computational steps of this solution is set down for easy reference.

Micko, H.C. A "HALO"-MODEL FOR MULTIDIMENSIONAL  
1970 RATIO SCALING. *Psychometrika*, 35, 199-227.

A model for direct multidimensional ratio scaling is presented, based on the concepts "common" and "difference" of the "halos" of two percepts. Measures of halos and their differences are proportional to lengths of corresponding percept vectors and their distance in subjective space. Ekman type scaling judgments are assumed to reflect the ratio measure of the common/measure of the standard's halo. The model is supposed to yield results that are in line with the results of distance models of multidimensional ratio scaling, since negative scalar products of percept vectors are admitted.

Micko, H.C. and Fischer, W. THE METRIC MULTIDIMENSIONAL  
1970 PSYCHOLOGICAL SPACES AS A FUNCTION OF THE DIFFERENTIAL ATTENTION TO SUBJECTIVE ATTRIBUTES. *J. math. Psychol.* 7(1), 118-43.

Metrics of subjective spaces are derived from a common rule of combination: To every direction in  $R^n$  is assigned a non-negative measure which reflects the importance of the corresponding attribute. Irrespective of the metric, an overall distance is obtained by projecting the distance vector in  $R^n$  on all directions of  $R^n$ , weighting the Euclidean lengths of these projections by the corresponding importance scores, and averaging the weighted projection lengths. A particular metric is determined by a particular distribution of importance scores over the directions of  $R^n$ . The city-block metric assigns importance scores = 0 to a set of mutually orthogonal directions only; the Euclidean metric assigns equal importance scores to all directions in  $R^n$ . The average of min-kowski metrics is again a Minkowski metric.

**Munsinger, H. MULTIVARIATE ANALYSIS OF PREFERENCE  
1966 FOR VARIABILITY. *J. Exper. Psychol.*, 71, 889-95.**

Two sets of studies are reported concerning the strategies of children and adults in the approach to variability of stimulation. Using (a) samples of random shapes differing in level of variability, (b) various age groupings, and (c) a multidimensional scaling procedure, evidence is presented that children and adults differ systematically in their preference for high stimulus variability. An explanation of the age difference is proposed in terms of a sampling strategy on the part of children in response to high stimulus variability. An implication of the sampling notion was explored by presenting pairs of shapes to adult subjects for judgments at very short exposure durations. It was expected that at shorter exposure durations the adults would adopt a sampling strategy similar to the younger children and thereby generate a preference-variability function comparable to younger children. The results confirmed this expectation.

**Murrell, J.F. MULTIDIMENSIONAL SCALING OF AN AIRCRAFT  
1969 HANDLING RATING SCALE. *Ergonomics*, 12(6), 925-33.**

The items of the Cooper aircraft handling rating scale were submitted to test pilots, who judged how far apart the items should be on the scale. The resulting single dimension scaling of the items does not give an equal interval scale. Analysis of the responses by different pilots indicates that problems arise in comparing ratings given by different users of the scale. Action to modify the scale is suggested but this is not proposed as a complete resolution of the problems raised.

**Nakatani, L.G. CONFUSION-CHOICE MODEL FOR MULTIDI-  
1972 MENSIONAL PSYCHOPHYSICS. *J. math Psychol.*, 9,  
104-27.**

The confusion-choice model for multidimensional psychophysics proposes the following abstraction of the stimulus recognition process. Each stimulus  $S_i$  and its correct response  $R_i$  are represented by a common point in a multidimensional subjective space of minimum dimensionality. Presentation of

$S_i$  yields a set of noisy proximity measures which indicate how close each response is to  $S_i$ . All the responses which are close enough to  $S_i$  according to proximity measures are considered acceptable; all other responses are unacceptable. The observer chooses a response at random from among the acceptable responses in accord with a choice probability distribution, which may not be uniform due to response bias. The model successfully predicts the confusion matrices for color and tone recognition experiments, including response bias effects in the data.

Norman, J.E. and David, H.A. RESTRICTED RANKING. *Psychometrika*, 34, 1969.

This paper is a study of certain aspects of restricted ranking, a method intended for use by a panel of  $m$  judges evaluating the relative merits of  $N$  subjects, candidates for scholarships, awards, etc. Each judge divides the  $N$  subjects into  $R$  classes so that  $n_i$  individuals received a grade  $i$  ( $i = 1, 2, \dots, R$ ;  $\sum n_i = N$ ) where the  $R$  numbers  $n_i$  are close to  $N/R$  ( $n_i = N/R$  when  $N$  is divisible by  $R$ ) and are preassigned and the same for all judges. This method is superior in several respects to other likely alternatives. Under the null hypothesis that all  $nR = N$  subjects are of equal merit, four tests of significance are developed. The effectiveness of the method is investigated both theoretically by means of the asymptotic relative efficiency and more generally by simulation studies. When the numbers  $n_i$  are not restricted to values close to or equal to  $N/R$ , but instead are given values conforming to a normally distributed pattern, the resulting method is known as the  $Q$ -sort, so designated by certain investigators in psychotherapy. The simulation studies reveal that restricted ranking is only slightly inferior to complete ranking and generally superior in the cases considered to the  $Q$ -sort, although there are likely to be other situations when the latter is superior.

Osborne, D.K. FURTHER EXTENSIONS OF A THEOREM OF DI-1970 MENSIONAL ANALYSIS. *J. math. Psychol.*, 7, 236-42.

This paper extends the Luce extension of the dimensional analysis theorem to cover ordinal and log interval scales. It

shows (1) that no complex of dimensionally distinct interval or log interval scales maps into an ordinal scale; (2) that a complex of dimensionally distinct ratio scales maps into a log interval scale only by the power function  $f(x_1, x_2, \dots) = K \prod_{i=1}^n x_i^{a_i}$ , where  $K$  is greater than 0 and  $a_i$  is not equal to 0 are arbitrary, and the function  $A \exp f(x_1, x_2, \dots)$ , where  $A$  is greater than 0 is arbitrary; and (3) a complex of ratio scales maps into an ordinal scale by any increasing monotonic function of  $f(x_1, x_2, \dots)$ , and by no other function. Adjoined to the Luce results, these complete the analysis of all combinations of "independent" and "dependent" scales of the ratio, interval, log interval, and ordinal type.

Pearson, K. ON LINES AND PLANES OF CLOSEST FIT TO  
1901 SYSTEMS OF POINTS IN SPACE. *Philosophical Magazine*,  
6(2), 559-72.

In many physical, statistical, and biological investigations, it is desirable to represent a system of points in plane, three, or higher dimensioned space by the "best-fitting" straight line or plane.

Richardson, M.W. MULTIDIMENSIONAL PSYCHOPHYSICS.  
1938 *Psychol. Bulletin*, 35, 659-60.

The traditional psychophysical methods are limited to one dimension or linear continuum. In those situations in which the basis for psychophysical judgments is a complex of variables instead of a single variable, it has been necessary to be content with an inferior one-dimensional approximation. The present study is concerned with the extension of psychophysical methods to more than one dimension..

Ross, J. A REMARK ON TUCKER AND MESSICK'S "POINTS OF  
1966 VIEW" ANALYSIS. *Psychometrika*, 31(1), 27-31.

It is shown that to combine readings from "points of view" configurations as assumed in Tucker and Messick's model is not to combine configurations in any simple way. Both empirical and logical consequences of the disparity are discussed.

Ross, J. THE RELATION BETWEEN TEST AND PERSON FACTORS. *Psychol. Review*, 70, 432-43.  
1963

There has been considerable dispute about whether  $R$  (test) and  $Q$  (person) factoring of the same data produces the same or different factors. This paper attacks the problem by considering the differences produced in factor configurations by operation on the data preliminary to or inherent in factoring one way or the other. It is concluded that although the nature of the factors does not change in any qualitative way, configurations may be altered sufficiently to make it appear that they have, and that it is therefore important to consider questions of sampling and measurement in evaluating the results of any factor analysis.

Ross, J. and DiLollo, V. A VECTOR MODEL FOR PSYCHOPHYSICAL JUDGMENT. *J. Exper. Psychol.*, 77(3), 1-6.  
1968

Rumelhart, D.L. and Greene, J.G. SIMILARITY BETWEEN STIMULI: AN EXPERIMENTAL TEST OF THE LUCE AND RESTLE CHOICE MODELS. *J. math. Psychol.*, 8, 370-81.  
1971

A set of choice alternatives was constructed to test Restle's (1961) hypothesis about the role of similarity between alternatives in choice behavior. The set contained names of three political figures, three actresses, and three athletes, with the intention of producing considerable similarity within subsets and minimal similarity between subsets. Subjects were asked to select the individual with whom they would prefer to spend an hour of conversation. Paired-comparison choice data from 234 college subjects were consistent with expectations based on Restle's model, and disconfirmed Luce's (1959) stronger model which does not take similarity into account. Measurements of response strength for choosing the individual alternatives, and of perceived similarity between pairs of alternatives can be obtained using Restle's model, and the present test provides evidence for the validity of such measurements. Finally, Restle's model is shown to be indistinguishable from a modification of Thurstone's (1927) Case V, where the assumption of zero correlation is relaxed to permit nonnegative correlations between pairs of discriminial dispersions.



Sayeki, Y. ALLOCATION OF IMPORTANCE: AN AXIOM SYSTEM.  
1972 *J. math. Psychol.*, 9, 55-65.

The proposed axiom system yields utility functions for different orderings of multidimensional objects, functions that, for each ordering, are expressed as sums of real-valued functions, called *constituent functions*, weighted by their corresponding *importance measure*. Each constituent function is a function specific to each dimension, and importance measures are positive or negative real numbers. It is shown that if the axioms hold, the constituent functions remain the same for all different orderings, while only the importance measures dictate the change of ordering. The axioms are stated in terms of a person's choice behavior under various circumstances.

Schoenemann, P.H. AN ALGEBRAIC SOLUTION FOR A CLASS OF SUBJECTIVE METRICS MODELS.  
1972 *Psychometrika*, 37, 441-51.

It is shown that an obvious generalization of the subjective metrics model by Bloxom, Horan, Carroll and Chang has a very simple algebraic solution which was previously considered by Merdith in a different context. This solution is readily adapted to the special case treated by Bloxom, Horan, Carroll and Chang. In addition to being very simple, this algebraic solution also permits testing the constraints of these models explicitly. A numerical example is given.

Schoenemann, P.H. ON METRIC MULTIDIMENSIONAL UNFOLDING.  
1970 *Psychometrika*, 35, 349-66.

The problem of locating two sets of points in a joint space, given the Euclidean distances between elements from distinct sets, is solved algebraically. For error free data the solution is exact; for fallible data it has least squares properties.

Schoenemann, P.H. and Wang, M.W. AN INDIVIDUAL DIFFERENCE MODEL FOR THE MULTIDIMENSIONAL ANALYSIS OF PREFERENCE DATA.  
1972 *Psychometrika*, 37, 275-308.

A model for the analysis of paired comparison data is presented which combines features of the BTL-model with features of the Unfolding model. The model is metric, mathematically tractable, and has an exact algebraic solution. Since it is multidimensional and allows for individual differences, it is thought to be more realistic for some choice situations than either the Thurstone model or the BTL-model. No claim is made that the present model will be appropriate for all conceivable choice situations. Rather, it is argued that the fact that it is explicitly falsifiable is a point in its favor.

Shanteau, J.C. and Anderson, N.H. TEST OF A CONFLICT MODEL  
1969 FOR PREFERENCE JUDGMENT. *J. math. Psychol.*, 6(2),  
213-325.

Subjects rated their preference between pairs of sandwiches, drinks, or sandwich-drink combinations. Use of factorial designs allowed simple tests of a subtractive model for preference. The results gave considerable support to the model, although some discrepancies were obtained. These seemed to stem partly from idiosyncratic discrepancies in a few subjects, partly from certain number preferences by the subjects as a group. In addition, two methods of estimating the scale values of the preference alternatives were compared. Model-based estimates appeared to be superior to independent ratings of the single alternatives. Finally, it was noted that the results tended to validate the use of rating scales to measure preference and, more generally, to support a functional theory of measurement.

Shepard, R.N. METRIC STRUCTURES IN ORDINAL DATA. *J.*  
1966 *math. Psychol.*, 3, 287-315.

Under appropriate conditions, data merely about the "ordering" of objects—or of the separations between objects—is sometimes sufficient to fix the positions of those objects on an essentially numerical scale. This paper uses both mathematical and "Monte Carlo" results to establish and clarify the possibility of thus extracting metric information from purely ordinal data for two multidimensional cases: Analysis of proximities, in which one is given a single rank order of all

$n(n - 1)/2$  pairs of  $n$  objects with respect to psychological similarity or "proximity"; and nonmetric factor analysis, in which one is given a different rank order of  $n$  different individual objects with respect to each of  $m$  psychological attributes. As  $n$  (and  $m$ ) increase, the ordinal data are found to determine a spatial representation of the objects more and more nearly within a general similarity transformation, in the case of nonmetric factor analysis. Extensions of these results to other cases are also considered.

Shepard, R.N. ANALYSIS OF PROXIMITIES AS A TECHNIQUE  
1963 FOR THE STUDY OF INFORMATION PROCESSING IN  
MEN. *Human Factors*, 5, 33-48.

Shepard, R.N. THE ANALYSIS OF PROXIMITIES: MULTIDIMEN-  
1962a SIONAL SCALING WITH AN UNKNOWN DISTANCE  
FUNCTION—I. *Psychometrika*, 27(2), 125-40.

A computer program is described that is designed to reconstruct the metric configuration of a set of points in Euclidean space on the basis of essentially nonmetric information about that configuration. A minimum set of Cartesian coordinates for the points is determined when the only available information specifies for each pair of those points—not the distance between them—but some unknown, fixed monotonic function of that distance. The program is proposed as a tool for reductively analyzing several types of psychological data, particularly measures of interstimulus similarity or confusability, by making explicit the multidimensional structure underlying such data.

Shepard, R.N. THE ANALYSIS OF PROXIMITIES: MULTIDIMEN-  
1962b SIONAL SCALING WITH AN UNKNOWN DISTANCE  
FUNCTION—II. *Psychometrika*, 27(3), 219-46.

The first in the present series of two papers described a computer program for multidimensional scaling on the basis of essentially nonmetric data. This second paper reports the results of two kinds of test applications of that program. The first application is to artificial data generated by monotonically transforming the interpoint distances in a known spatial

configuration. The purpose is to show that the recovery of the original metric configuration does not depend upon the particular transformation used. The second application is to measures of interstimulus similarity and confusability obtained from some actual psychological experiments.

Shepard, R.N. and Carroll, J.D. PARAMETRIC REPRESENTATION  
1966 OF NONLINEAR DATA STRUCTURES. *In* P.R. Krishnaiah,  
*Multivariate Analysis I*, 561-92.

A problem that arises in many different contexts is that of determining the smallest set of "independent" variables necessary to account for a redundant set of observed variables. Principal-components analysis or linear factor analysis are ideally suited to deal with this problem when the redundancy of the observed variables is attributable to their "linear" dependence on a smaller set of underlying variables. In a variety of applications of scientific interest, however, this dependence is severely nonlinear. In such cases, these existing techniques will fail to reduce the observed variables to an optimally parsimonious representation; the number of recovered dimensions will necessarily exceed the true degrees of freedom inherent in the data. The thesis of this paper is that solutions to this more general, nonlinear problem are feasible only provided that the functional dependence of the observed variables on the underlying "latent" variables is sufficiently smooth or "continuous". Two different approaches to this problem are presented, together with illustrative applications. Both approaches use iterative processes on a digital computer to find a representation of the vectors of observed variables as points in a Euclidean space of the smallest possible dimensionality.

Shepard, R.N. and Chipman, S. SECOND-ORDER ISOMORPHISM  
1970 OF INTERNAL REPRESENTATIONS: SHAPES OF  
STATES. *Cognitive Psychology*, 1, 1-17.

It is argued that, while there is no structural resemblance between an individual internal representation and its corresponding external object, an approximate parallelism should nevertheless hold between the relations among different

internal representations and the relations among their corresponding external objects. In support of this "second-order" type of isomorphism, subjective judgments of the similarities among the shapes of 15 states of the U. S. are found (a) to be very much the same whether the states to be compared are pictorially displayed or only imagined, and (b) to be related, in both cases to identifiable properties of their actual cartographic shapes.

**Sherman, C.R. NONMETRIC MULTIDIMENSIONAL SCALING: A  
1972 MONTE CARLO STUDY OF THE BASIC PARAMETERS.**  
*Psychometrika*, 37, 323-55.

Metric determinacy of nonmetric multidimensional scaling was investigated as a function of the number of points being scaled, the amount of error in the data being scaled, and the accuracy of estimation of the Minkowski distance function parameters, dimensionality and the  $r$ -constant. It was found that nonmetric scaling may provide better models if (1) the true structure is of low dimensionality, (2) the dimensionality of recovered structure is not less than the dimensionality of the true structure, (3) degree of error is low, and (4) the degrees of freedom ratio is greater than about 2.5. It was also found that (5) accurate estimation of the Minkowski constant leads to a better model only if the dimensionality has been properly estimated.

**Sjoberg, L. THE DIMENSIONALITY PARADOX IN COMPARA-  
1968 TIVE JUDGMENT: A RESOLUTION.** *Scand. J. Psychol.*, 9,  
97-108.

It has often been possible to erect unidimensional scales even when stimuli have been clearly multidimensional. This fact is surprising since one expects the multidimensional structure to be reflected in the data. It is suggested that this structure might be recovered from dispersions of comparative judgments. The suggestion is shown to be valid on three sets of paired comparison data. Implications for uni- and multidimensional scaling are discussed.

Skager, R.W., Schultz, C.B. and Klein, S.P. THE MULTIDIMENSIONAL SCALING OF A SET OF ARTISTIC DRAWINGS: PERCEIVED STRUCTURE AND SCALE CORRELATES. *Multivariate Behavioral Research* 1(4), 425-36.

Product-centered research on creativity approaches the criterion problem of what is to be the referent for creativity through the analysis of tangible products such as art objects, writing, or scientific achievements. The present research is concerned with the evaluation and study of artist drawings contributed by sophomore students at the Rhode Island School of Design. Multidimensional scaling methods were applied to similarity judgments obtained from art experts on two separate sets of 25 drawings. Three similarity dimensions accounted for the interstimulus distances for each set of drawings. Although no statistical test was available, the dimensions from the two sets appeared to correspond. Scale values of 4 drawings common to the two sets were consistent, and the dimensions appeared to define very similar stimulus characteristics. It was concluded that multidimensional scaling procedures provided a means for differentiating among a set of complex, esthetic products. Scale values of drawings on the three dimensions also correlated differentially with cognitive and achievement measures available on the students, suggesting that product dimensions identified via similarity judgments were related to characteristics of individuals producing the products. Hypotheses were developed as to the psychological meaning of the three product dimensions.

Slater, R. THE ANALYSIS OF PERSONAL PREFERENCES. *Brit. J. stat. Psychol.*, 13, 119-35.

A procedure is explained for the construction of preference tables which set out in a systematic scheme the results obtained by using the method of ranks, paired comparison, or some other type of multiple comparison; the detailed properties of such tables are described. Such a table may be used to exhibit the dispersion of objects in a multidimensional space of individuals' preferences or the dispersion of individuals in a space of preferences for objects. The two devices are shown

to be complementary. Methods of analyzing and studying tables of this kind are discussed and illustrated..

**Solomon, L.N. SEARCH FOR PHYSICAL CORRELATES TO  
1959a PSYCHOLOGICAL DIMENSIONS OF SOUNDS.** *J. Acoustic Soc. Amer.*, 31, 492-97.

Twenty passive sonar recordings were ranked by fifty subjects in terms of their aurally perceived (psychological) characteristics on seven different dimensions. Correlations were run between octave band sound pressure level measurement of the sounds and their rank orders on the seven psychological dimensions. Meaningful relationships were found between ranks on certain psychological dimensions and energy concentration within certain octave bands. Also an analysis was made of the manner in which the twenty sounds clustered within the space defined by the seven psychological dimensions. Analyses of these sound clusters revealed that the rhythmic beat pattern of the stimulus is a principal attribute upon which sonar men base their judgments of similarity.

**Solomon, L.N. SEMANTIC REACTIONS TO SYSTEMATICALLY  
1959b VARIED SOUNDS.** *J. Acoustic Soc. Amer.*, 31(7), 986-89.

Noise bands simulating passive sonar sounds were varied in terms of "spectrum" (band passed from 150-600 cps, or 600-2400 cps, or 2400-9600 cps); in terms of amplitude modulation (simulated screw beats) at "beat rates" of 0, 3, 5, or 11 per second; and in terms of presence or absence of "accent" within a group of four beats. Every combination of these parameters (twenty-one in all, not twenty-four, since at zero beat rate there can be no accent) was rated by twenty subjects in terms of their aurally perceived characteristics on fifteen scales representing seven different dimensions. Analysis was made of the manner in which the twenty-one sounds clustered within the space defined by the seven psychological dimensions. Two major clusters of sounds were observed, differentiated primarily on the basis of band pass condition (high frequency versus low frequency). Exceptions to this

general rule were analyzed to reveal the interactions between band pass condition, beat rate, and accent.

**Solomon, L.N. SEMANTIC APPROACH TO THE PERCEPTION OF  
1958 COMPLEX SOUNDS.** *J. Acoustic Soc. Amer.*, 30, 421-25.

In an attempt to derive a limited number of descriptive adjectives with which to characterize passive sonar sounds, 50 U.S. Navy sonarmen (median sonar experience of one year) rated twenty different passive sonar sounds on fifty seven-point scales defined by polar-opposite adjectives (e.g., heavy-light). The intercorrelations between scales (calculated over both subjects and sounds) were factor analyzed by the Thurstone complete centroid method. Seven interpretable orthogonal factors (accounting for approximately 40% of the variance of judgments) were extracted from the data. The generality of the methodology for psychological research on auditory perceptions is considered and suggestions for research along these lines are presented.

**Spence, I. A MONTE CARLO EVALUATION OF THREE NON-  
1972 METRIC MULTIDIMENSIONAL SCALING ALGORITHMS.**  
*Psychometrika*, 37, 461-86.

As a consequence of the complexity of the iterative optimum seeking procedures used by practical nonmetric multidimensional scaling algorithms, many of their computational properties have not been well understood. In particular, the following questions are of interest: (a) from the user's point of view, are there significant differences between alternative available programs, (b) are suboptimal solutions frequently encountered, and how does this depend on the characteristics of the algorithm? Using Monte Carlo techniques to generate dissimilarity matrices with known underlying configurations, Kruskal's M-D-SCAL, Guttman-Lingoe's SSA-I, and Young-Torgerson's TORSCA-9 programs were compared. It was found: (a) that differences between the solutions obtained by the algorithms were typically so small as to be of little practical importance, (b) deviant solutions were occasionally produced by each of the algorithms, but most often by M-D-SCAL, and furthermore, most frequently in one dimen-



sion. The likelihood of being trapped in a nonoptimal position is reduced by a good choice of initial configuration, and also possibly by constructing the iterative process to favor the possibility of stepping over small local depressions when far from the location of the optimum. The conclusions of this study are based on a total of 2160 scaling solutions.

**Stenson, H.H. and Knoll, R.L. GOODNESS-OF-FIT FOR RANDOM  
1969 RANKINGS IN KRUSKAL'S NONMETRIC SCALING PROCEDURE.** *Psychol. Bulletin*, 71, 122-26.

Random input data were analyzed with Kruskal's nonmetric scaling program in order to establish null hypothesis for the goodness-of-fit measure. Various numbers of hypothetical stimuli were analyzed using the Euclidean distance metric in various dimensionalities. The effects of tied ranks were studied.

**Stone, L.A. and Coles, G.J. DIMENSIONS OF COLOR VISION RE-  
1971 VISITED.** *J. of Psychol.*, 77, 79-87.

**Taylor, J.B. RATING SCALES AS MEASURES OF CLINICAL  
1968 JUDGMENT: A METHOD FOR INCREASING SCALE RELIABILITY AND SENSITIVITY.** *Educ. and Psychol. Measurement*, 28(3), 747-66.

Rating scales are perhaps the most commonly used measurement techniques in psychology, and certainly the most neglected. Their seeming simplicity may have worked against them: anybody can construct a rating scale, but it takes research sophistication to develop satisfactory multi-item measures. As a result, this area of psychometrics has been slighted, while other more glamorous areas have received much more attention. Yet rating scales may have potentialities hitherto overlooked. The authors consider several ways in which rating scales can be improved and their performance brought to the level of other measurement techniques. The initial applications seem promising: with the techniques presented in this paper rating scales have shown a marked increase in interjudge reliability and a marked decrease in response-set error, even with highly complex clinical judg-

ments. The techniques themselves are notably simple, convenient, and economical, and should be applicable to a wide range of problems.

Thomas, H. SPATIAL MODELS AND MULTIDIMENSIONAL  
1968 SCALING OF RANDOM SHAPES. *Amer. J. Psychol.* 81(4),  
551-8.

Eighth grade children ( $N = 232$ ) and college adults ( $N = 218$ ) made similarity judgments to 20 random shapes varying in complexity. The judgments were scaled using Kruskal's non-metric scaling procedure. For both groups the data fit a Euclidean solution as well as or better than various Minkowski metrics, for varying numbers of dimensions. In particular, the data most poorly fit the 'city-block' metric. Results indicated the data can be accounted for in either a one- or two-dimensional space. The first dimension was labeled 'complexity'; the second dimension was tentatively labeled 'symmetry.'

Torgerson, W.S. MULTIDIMENSIONAL SCALING OF SIMILAR-  
1965 ITY. *Psychometrika*, 30, 379-93.

Torgerson, W.S. DISTANCE AND RATIOS IN PSYCHOPHYSICAL  
1961 SCALING. *Acta Psychologica*, 19, 201-205.

In spite of all of the research that has been carried out over the past 100 years, an empirical answer to the question of the form of the psychophysical law is not yet available. Fechner's sensitivity approach leads to a logarithmic relation, as do the related discriminability models of Thurstone and Garner. The magnitude and ratio estimation methods, on the other hand, lead to a power relation. Which is correct? If what I suspect to be so is the case, the issue cannot be decided on empirical grounds, because an empirical basis for the decision simply does not exist. Though we can, of course, choose to regard one or the other as the correct form, if we do, it will only be a decision, not a discovery. In order to show why this seems to be so, it is necessary to look at some of the characteristics of the number system that we use in developing a scale of an attribute: numbers from two different commutative groups—

one with respect to the operation of addition, and one with respect to the operation of multiplication. They also have the characteristic that multiplication distributes over addition. These two commutative groups plus the distributive law are all we need for ordinary algebra.

**Torgerson, W.S. THEORY AND METHODS OF SCALING.** New 1958 York: Wiley and Sons.

**Tucker, L.R. RELATIONS BETWEEN MULTIDIMENSIONAL SCALING AND THREE-MODE FACTOR ANALYSIS.** *Psychometrika*, 37, 3-27.

A combination is achieved of two lines of psychometric interest: a) multidimensional scaling and b) factor analysis. This is accomplished with the use of three-mode factor analysis of scalar product matrices, one for each subject. Two of the modes are the groups of objects scaled and the third mode is the sample of subjects. Results are an object space, a person space, and a system for changing weights given dimensions and of angles between dimensions in the object space for individuals located at different places in the person space. The development is illustrated with data from an adjective similarity study.

**Tucker, L.R. SOME MATHEMATICAL NOTES ON THREE-MODE FACTOR ANALYSIS.** *Psychometrika*, 31, 279-311.

The model for three-mode factor analysis is discussed in terms of newer applications of mathematical processes including a type of matrix process termed the "Kronecker product" and definition of combination variables. Three methods of analysis to a type of extension of principal components analysis are discussed. Two methods are applicable to analysis of data collected for a large sample of individuals. An extension of the model is described in which allowance is made for unique variance for each combination variable when the data are collected for a large sample of individuals.

**Tucker, L.R. INTRAINDIVIDUAL AND INTERINDIVIDUAL MULTIDIMENSIONALITY.** In Gulliksen and Messick,

*Psychological Scaling: Theory and Applications.* New York: Wiley and Sons.

Quantitative study of psychological phenomena traditionally has analyzed the problems into two aspects: generalized laws of response to varying stimulus conditions, and laws for individual differences in responses to given stimuli. This analysis arises quite naturally from the duality of characteristics of the individual and of his environment. Each individual brings to the psychological experiment his various capabilities and predispositions, his attitudes and personality traits and, indeed, his protoplasmic make-up. In contrast, the experimental environment is more or less under the control of the experimenter who may devise the sequence of particular stimuli and form of the responses to be made by the individual. The experimenter may endeavor to establish certain sets in the individual by instruction or by experimental manipulation. In a classical experiment on reaction time, for example, the subject may be trained to take a motor set such that he is primed to react whenever a stimulus triggers this action. An observed response thus depends on (a) the stimulus condition, and (b) the individual. Differential emphasis between these two aspects has led to two corresponding lines of developments.

Tucker, L.R. and Messick, S. AN INDIVIDUAL DIFFERENCES  
1963 MODEL FOR MULTIDIMENSIONAL SCALING. *Psychometrika*, 28(4), 333-67.

A quantitative system is presented to permit the determination of separate multidimensional perceptual spaces for individuals having different viewpoints about stimulus interrelationships. The structure of individual differences in the perception of stimulus relationships is also determined to provide a framework for ascertaining the varieties of consistent individual viewpoints and their relationships with other variables.

Tversky, A. INTRANSITIVITY OF PREFERENCES. *Psychol. Rev.*,  
1969 76(1), 31-48.

It is shown that, under specified experimental conditions, consistent and predictable intransitivities can be demonstrated. The conditions under which intransitivities occur and their relationships to the structure of the alternatives and to processing strategies are investigated within the framework of a general theory of choice. Implications for the study of preference and the psychology of choice are discussed.

**Tversky, A. and Krantz, D.H. THE DIMENSIONAL REPRESENTATION AND THE METRIC STRUCTURE OF SIMILARITY DATA. *J. math. Psychol.*, 7, 572-96.**

A set of ordinal assumptions, formulated in terms of a given multidimensional stimulus set, is shown to yield an essentially unique additive difference measurement of dissimilarity, or psychological distance. According to this model, dissimilarity judgments between multidimensional objects are regarded as composed of two independent processes: an intradimensional subtractive process, and an interdimensional additive process. Although the additive difference measurement model generalizes traditional metric models, the conditions under which it satisfies the metric axioms impose severe restrictions on the measurement scales. The implications of the results for the representation of similarity data by metric and/or dimensional models are discussed.

**Tversky, A. and Krantz, D.H. SIMILARITY OF SCHEMATIC 1969 FACES: A TEST OF INTERDIMENSIONAL ADDITIVITY. *Perception and Psychophysics*, 5(2), 124-28.**

In this study we obtained direct and comparative judgments of the dissimilarity between schematic faces varying on three binary attributes. These data were used to test the hypothesis that the overall dissimilarity between faces can be decomposed (in an ordinal sense) into three additive components, one for each attribute. The hypothesis was strongly confirmed by both the direct and the comparative judgments. The study illustrates the possible usefulness of the measurement-theoretic analysis of simple combination rules for psychological dimensions.

Walters, H.A. and Jackson, D.N. GROUP AND INDIVIDUAL REG-  
1966 ULARITIES IN TRAIT INFERENCE: A MULTIDIMEN-  
SIONAL SCALING ANALYSIS. *Multivariate Behavioral Re-  
search*, April, 145-63.

This study concerned regularities in trait inference, the manner in which limited information about another person is used to form a consistent total impression. An individual differences model for multidimensional scaling was appraised as a method for faithfully structuring both broad culturally-determined standards, and differently-structured points of view. Judgments of likelihood of joint occurrence of trait pairs and measures of cognition were obtained from 139 subjects. Scaling analyses resulted in two points of view, the largest of which yielded dimensions of interpersonal affectivity, harmfulness, and charitableness. Separate analyses of randomly divided groups yielded indices of dimension stability ranging up to .99. The results support the view that the multidimensional scaling model can serve well to explain and order trait inference data.

Wedin, L. DIMENSION ANALYSIS OF THE PERCEPTION OF  
1969 MUSICAL STYLE. *Scand. J. Psychol.*, 10, 97-108.

The subjective similarity of ten short excerpts from musical works ranging over the period of 1720-1890 was studied by (1) the direct multidimensional ratio scaling method and (2) by the method of similarity analysis. Factor analysis extracted three or four factors depending on the degree of musical training of the subjects. The differentiation and interpretability of the factors were higher for subjects with more musical training and interest. The factors were labeled 'Baroque,' 'Rococo,' 'Viennese classicism,' and 'Romanticism.'

Wilk, M.B. and Gnanadesikan, R. GRAPHICAL METHODS FOR IN-  
1964 TERNAL COMPARISONS IN MULTIRESPONSE EXPERI-  
MENTS. *Annals Math. Statist.*, 35, 613-31.

Wish, M. COMPARISONS AMONG MULTIDIMENSIONAL STRUC-  
1970 TURES OF NATIONS BASED ON DIFFERENT MEA-  
SURES OF SUBJECTIVE SIMILARITY. *General Systems*,  
15, 55-56.

Young, F.W. NONMETRIC MULTIDIMENSIONAL SCALING: RE-  
1970 COVERY OF METRIC INFORMATION. *Psychometrika*, 35,  
455-73.

The degree of metric determinancy afforded by nonmetric multidimensional scaling was investigated as a function of the number of points being scaled, the true dimensionality of the data scaled, and the amount of error contained in the data being scaled. It was found (1) that if the ratio of the degrees of freedom of the data to that of the coordinates is sufficiently large, then metric information is recovered even when the random error is present; and (2) when the number of points being scaled increases, the stress of the solution increases even though the degree of metric determinancy increases.

Young, F.W. and Cliff, N. INTERACTIVE SCALING WITH INDI-  
1972 VIDUAL SUBJECTS. *Psychometrika*, 37, 385-415.

A metric multidimensional scaling (MDS) procedure based on computer-subject interaction is developed, and an experiment designed to validate the procedure is presented. The interactive MDS system allows generalization of current MDS systems in two directions: (a) very large numbers of stimuli may be scaled; and (b) the scaling is performed with individual subjects, facilitating the investigation of individual as well as group processes. The experiment provided positive support for the interactive MDS system. Specifically, (a) individual data are amenable to meaningful interpretation, and they provide a tentative basis for quantitative investigation; and (b) grouped data provide meaningful interpretive and quantitative results which are equivalent to results from standard paired-comparisons methods.

Young, G. and Householder, A.S. A NOTE ON MULTIDIMENSION-  
1941 AL PSYCHOPHYSICAL ANALYSIS. *Psychometrika*, 6.

On viewing Thurstone's psychophysical scale from the point of view of the mathematical theory of one-parameter continuous groups, it is seen that a variety of different psychological or statistical assumptions can all be made to lead to a

scale possessing similar properties, though requiring different computational techniques for their determination. The natural extension to multi-dimensional scaling is indicated.

**Young, G. and Householder, A.S. DISCUSSION OF A SET OF 1938 POINTS IN TERMS OF THEIR MUTUAL DISTANCES.**  
*Psychometrika*, 3, 12-22.

Necessary and sufficient conditions are given for a set of numbers to be the mutual distances of a set of real points in Euclidean space, and matrices are found whose ranks determine the dimension of the smallest Euclidean space containing such points. Methods are indicated for determining the configuration of these points, and for approximating to them by points in a space of lower dimensionality.



## Chapter II

### SINGLE ATTRIBUTE SCALING

The previous section on multidimensional scaling, although more specialized in its coverage, includes many items which discuss the problem of scaling in general. They should, therefore, also be consulted in any study of environmental scaling. In addition, there are many items dealing with scaling which should be mentioned, although they do not use multidimensional techniques. Some of the most important work along these lines is included in this chapter under the general title, *Single Attribute Scaling*.

Torgerson, in *Theory and Methods of Scaling*, collected much material. This work has been extended by Gulliksen and Messick in *Psychological Scaling: Theory and Application*. While many procedures for the analysis of test scores have been evolved, little effort has been directed at scaling the environment, except for the work of sensory psychologists such as Stevens, and those who have taken his work as a basis for further research. Much work has been done in fundamental measurement, especially conjoint measurement theory (Ellis and Luce, for example). This work is summarized and extended in *Foundations of Measurement* by Krantz, Luce, Suppes and Tversky (New York, Academic Press, 1971).

### SINGLE ATTRIBUTE SCALING

Adams, E.W., Fagot, R.F. and Robinson, R.E. ON THE EMPIRICAL  
1970 STATUS OF AXIOMS IN THEORIES OF FUNDAMENTAL  
MEASUREMENT. *J. math. Psychol.*, 7, 379-409.

If one regards the purpose of axiomatization in fundamental measurement theory as being that of exhibiting directly testable sets of conditions (the axioms) that are necessary and/or sufficient guarantee the existence of numerical representations (numerical measurements) of certain kinds, then it should be clear that most of the axiom systems that have been given in measurement theory do not realize this objective. This raises the question of precisely what the *empirical content* is of axioms in theories of fundamental measurement. The basic concept in terms of which the formal results of the authors are stated is that of *data equivalence* between two theories. Roughly, two theories are data equivalent if and only if they are consistent with exactly the same finite sets of basic "observation" statements. The significance of data equivalence is that if two theories are data equivalent and their primitive notions are given the same interpretation, then no experimental test can refute one without refuting the other. The authors are able to show, for example, that certain axioms (Archimedean and continuity conditions) are purely "technical" in the sense that the theory with the axiom in question is data equivalent to the theory without the axiom, whereas certain other axioms, previously treated as technical,

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are indirectly testable; i.e., have testable consequences when considered in combination with other directly testable axioms. The concept of data equivalence is used to analyze the Luce-Tukey axioms for conjoint measurement, axiom systems for interval measurement, for additive and bisection (Pfanzagl), and for extensive measurement (Suppes).

**Anderson, N.H. FUNCTIONAL MEASUREMENT AND PSYCHO-  
1970 PHYSICAL JUDGMENT.** *Psychol. Review*, 77, 153-70.

Functional measurement theory is applied to four experimental situations in psychophysical scaling. Two judgment models are considered: additive and multiplicative. These are first applied to a psychophysical averaging task and to a ratio estimation task in which the numerical response is assumed to be a valid and proper measure of subjective magnitude. It is shown that factorial designs and analysis of variance procedures not only provide tests of the models but also scales of the independent, stimulus variables. Next multisection (including bisection) and ratio setting tasks are considered. For these, the response is on the physical stimulus scale, and this is not in general an adequate psychological scale. However, the monotone rescaling procedure of functional measurement provides a way to get a valid scale of the dependent, response variable. A robust method for distinguishing between the log and power versions of the psychophysical law is also obtained. Finally, it is argued that the experimental base of traditional psychophysical scaling with direct, numerical response methods is inherently too narrow to support a solution to its problems. Tasks based on psychophysical information integration provide a broader and potentially simpler approach to scaling. In this approach, the psychophysical law appears as a by-product of the substantive development.

**Atkinson, R.C., Carterette, E.C. and Kinchla, R.A. SEQUENTIAL  
1962 PHENOMENA IN PSYCHOPHYSICAL JUDGMENTS A  
THEORETICAL ANALYSIS.** Stanford University Institute  
Mathematical Studies, Soc. Sci. Tech. Report 46.

**Atteneve, F. and Chambliss, D.J. AN IMPROVED METHOD FOR  
1957 DERIVING EQUAL-DISCRIMINABILITY SCALES FROM  
RATINGS.** *Psychol. Bulletin*, 54, 253-55.

Barnhart, E.N. A COMPARISON OF SCALING METHODS FOR  
1936 AFFECTIVE JUDGMENTS. *Psychol. Rev.*, 43(5), 387-95.

Bendig, A.W. THE RELIABILITY OF SELF-RATINGS AS A FUNC-  
1953 TION OF THE AMOUNT OF VERBAL ANCHORING AND  
OF THE NUMBER OF CATEGORIES ON THE SCALE. *J.  
Applied Psychol.*, 37(1), 38-41.

Bendig, A.W. and Hughes, J.B. EFFECT OF AMOUNT OF VERBAL  
1953 ANCHORING AND NUMBER OF RATING-SCALE CATE-  
GORIES UPON TRANSMITTED INFORMATION. *J. Exper.  
Psychol.*, 46(2), 87-90.

Boring, E.G. FECHNER: INADVERTENT FOUNDER OF PSYCHO-  
1961 PHYSICS. *Psychometrika*, 26, 3-8.

Boring, E.G. THE STIMULUS ERROR. *Amer. J. Psychol.*, 32,  
1921 449-71.

Ebel, R.L. ESTIMATION OF RELIABILITY OF RATINGS. *Psycho-*  
1951 *metrika*, 16(4), 407-24.

A procedure for estimating the reliability of sets of ratings, test scores, or other measures is described and illustrated. This procedure, based upon analysis of variance, may be applied both in the special case where a complete set of ratings from each of  $k$  sources is available for each of  $n$  subjects, and in the general case where  $k_1, k_2, \dots, k_n$  ratings are available for each of the  $n$  subjects. It may be used to obtain either a unique estimate or a confidence interval for the reliability of either the component ratings or their averages. The relations of this procedure to others intended to serve the same purpose are considered algebraically and illustrated numerically.

Edwards, A.L. and Kilpatrick, F.P. SCALE ANALYSIS AND THE  
1948 MEASUREMENT OF SOCIAL ATTITUDES. *Psychometrika*,  
13(2), 99-114.

This paper discusses and compares the methods of attitude scale construction of Thurstone (method of equal-appearing intervals), Likert (method of summated ratings), and Gutt-

man (method of scale analysis), with special emphasis on the latter as one of the most recent and significant contributions to the field. Despite a certain lack of methodological precision, scale analysis provides a means of evaluating the unidimensionality of a set of items. If the criteria for unidimensionality are met, the interpretation of rank-order scores is made unambiguous, and efficiency of prediction from the set of items is maximized. The Guttman technique, however, provides no satisfactory means of selecting the original set of items for scale analysis. Preliminary studies indicated that both the Likert and Thurstone methods tend to select scalable sets of items and that their functions in this respect are complementary. A method of combining the Likert and Thurstone methods in order to yield a highly scalable set of items is outlined. Sets of fourteen items selected by the method have, in the two cases where the technique has been tried, yielded very satisfactory scalability.

Eisler, H. ON THE PROBLEM OF CATEGORY SCALES IN 1962 PSYCHOPHYSICS. *Scand. J. Psychol.*, 3, 81-87.

In the first part of the paper it is shown that, if three assumptions are granted, the category scale must be logarithmically related to the magnitude scale:  $K = a \log \psi + \beta$ . In the second part of the paper, the relation  $K = a \log(k\psi + q) + \beta$  is derived, starting from the assumptions that the category scale is a pure function of discrimination and that discrimination is appropriately described by the linear generalization of Weber's law for prothetic continua. These two formulas are then reconciled by defining the zero-point of the magnitude scale as the point where variability vanishes.

Ekman, G., Hosman, B., Lindman, R., Ljunberg, L. and Akarson, C. 1967 INTERINDIVIDUAL DIFFERENCES IN SCALING PERFORMANCE. Rep. Psychol. Lab., University of Stockholm, No. 241.

Twenty-one subjects performed complete ratio estimation of seven stimuli in each of six continua. Individual scales were constructed and condensed into a measure of scale range. The coefficients of correlation between continua were positive

and mostly statistically significant but much lower than the coefficients of reliability. The results support a two-factor hypothesis, according to which individual differences in scaling behavior reflect both a genuine perceptual variability and differences in response bias.

**Ekman, G. and Kunnapas, T. A FURTHER STUDY OF DIRECT  
1963 AND INDIRECT SCALING METHODS. *Scand. J. Psychol.*,  
4, 77-80.**

The direct method of ratio estimation and the indirect method of pair comparisons were used to construct scales of the political importance of eleven Swedish monarchs. The scale from pair comparisons on the assumption of Case V was a logarithmic transformation of the ratio estimation scale. This is in line with the results obtained in several previous studies.

**Ekman, G. and Kunnapas, T. MEASUREMENT OF AESTHETIC  
1962 VALUE BY 'DIRECT' AND 'INDIRECT' METHODS. *Scand.  
J. Psychol.* 3(1), 33-39.**

The main features of 'direct' and 'indirect' methods for psychophysical measurement are briefly reviewed. An experiment is described, where the aesthetic value of 18 specimens of handwriting was measured by the direct method of ratio estimation and the indirect method of pair comparisons on the assumption of Thurstone's Case V. The scale constructed by the indirect method was a theoretically expected logarithmic function of the ratio scale obtained by the direct method. If the ratio scale is accepted as a criterion, the results show that a true interval scale may be constructed by the indirect method, in this experiment, provided that the assumption of constant variability is replaced by an assumption of proportional variability.

**Ellis, B.D. BASIC CONCEPTS OF MEASUREMENT. Cambridge,  
1966 Mass.: Cambridge University Press.**

**Eyman, R.K. THE EFFECT OF SOPHISTICATION ON RATIO  
1967 AND DISCRIMINATION SCALES. *Amer. J. Psychol.*, 80,  
520-40.**

Garner, W.R. RATING SCALE, DISCRIMINABILITY, AND INFORMATION TRANSMISSION. *Psychol. Rev.*, 67(6), 1960, 343-52.

The purpose of this paper is to show how information transmission measures and discriminability scales can be used to determine the optimum number of rating categories. An illustrative set of data were obtained for 20 samples of handwriting with 4, 6, 8, 10, 12, 16 and 20 rating categories. Information transmission measures, after correction for sampling bias, show a small but definite increase in discrimination up to the 20 categories used. Discriminability scale values were also constructed from the rating data, and the standard deviations of the scale values show the same increase in discrimination. The variance of the discriminability scale values can be used to estimate information transmission, and the estimates agree very well with the directly calculated information measures. It is pointed out that the optimum number of rating categories must depend on the discriminability inherent in the particular rated stimuli, and the optimum number of categories will be large compared to the measured information transmission.

Garner, W.R. and Hake, H.W. THE AMOUNT OF INFORMATION IN ABSOLUTE JUDGMENTS. *Psychol. Rev.*, 58, 1961, 446-59.

With absolute judgments, or stimulus ratings of stimulus categories, the judgments of an *O* indicate how accurately the *O* perceived which of the several alternative stimuli occurred on a particular presentation, or how much information the *O* obtained about which stimulus occurred. The amount of information which the stimuli transmit to an *O* can be measured in bits. This measure gives an estimate of the minimum number of stimulus categories which can be used to transmit the maximum amount of information in those cases where the coding of the events to a symbol can be done with no error. The contingency coefficient has some of the same properties as the amount of information. In order to select the stimuli for maximum information transmission, a scale of equal discriminability is required, and a technique for constructing such a scale is described. The scale of equal discrimi-

nability can also be used to select stimuli which will partially compensate for an unequal frequency distribution of the events being represented.

**Green, D.M. PSYCHOACOUSTICS AND DETECTION THEORY. J. 1966** *Acoustic Soc. Amer.*, 32(10), 1189-1203.

This paper presents a fairly complete review of detection theory as it is applied to certain psychoacoustic data. Detection theory is treated as a combination of two theoretical structures: decision theory and the concept of the ideal observer. The paper discusses how statistical decision theory has been used to analyze the auditory threshold process. By treating the threshold process as an instance of hypothesis testing, two determinants of the process are recognized: (1) the detectability of the signal and (2) the criterion level of the observer. The theory provides a technique of analysis which allows one to obtain a quantitative estimate of both factors. The measure of signal detectability appears to be independent of the psychophysical procedure when the physical parameters of signal and noise are held constant. The concept of ideal observer is reviewed with special emphasis on the assumptions of the derivation. The usefulness of this concept is illustrated by considering the shape of the psychophysical function—the function relating the detectability of the signal to its intensity. A rather general model based on the concept of signal uncertainty is presented which attempts to explain this relationship.

**Gulliksen, H. and Messick, S. (Eds.) PSYCHOLOGICAL SCALING: 1960** THEORY AND APPLICATION. New York: John Wiley and Sons.

**Guttman, L. A BASIS FOR SCALING QUALITATIVE DATA. 1943** *Amer. Soc. Rev.*, 9(2), 139-50.

**Hopkinson, R.G. INFLUENCE OF EXPERIENCE ON THE SENSITIVITY TO DISCOMFORT. 1952** *Nature*, 169, 40.

The sensitivity of a subject to discomfort arising from his environment may be dependent in some degree on his



familiarity with, or technical knowledge of, the environment. Some evidence to this effect has accumulated from a long series of field studies of lighting. A subject may be unconscious of glare from a bare lamp over his desk until his attention is directed to it, but thereafter may become aware of glare-discomfort in other environments as well. Other workers have recorded similar effects.

Jones, F.N. and Marcus, M.J. THE SUBJECT EFFECT IN JUDG-  
1961 MENTS OF SUBJECTIVE MAGNITUDE. *J. Exper. Psychol.*,  
61(1), 40-4.

Forty-nine subjects judged the subjective intensities of a series of weights, tastes and smells by the method of magnitude estimation. Individual curves of the form  $R = aS^b$  were fitted for each  $S$  for each modality and for each two runs, here referred to as orders. Analysis of variance of the exponents,  $b$ , obtained reveals: (a) significant primary effects of Subjects and Modalities, (b) a significant interaction between Modality and Subjects and (c) the removal of the interaction in the case of taste and weight by adjusting the average  $b$  for the two modalities to equality. A multiplicative model being appropriate, the power law of Stevens is revised to include an individual exponent, hence  $R = aS^{b_i} c_i$  where  $c_i$  is appropriate to a given  $S$ . A discussion of averaging to obtain group curves reveals that either a logarithmic transform prior to averaging or the geometric mean are logically correct, although the use of medians should not introduce great distortion.

Jones, F.N. and Woskow, M.J. SOME EFFECTS OF CONTEXT ON  
1966 THE SLOPE IN MAGNITUDE ESTIMATION. *J. Exper.*  
*Psychol.*, 71, 170-76.

Junge, K. THE PROBLEM OF MAGNITUDE AND CATEGORY  
1962 SCALES: INTERPRETATION OF RESULTS. *Scand. J.*  
*Psychol.* 3(4), 215-18.

It is proposed that three main factors are responsible for the relation between magnitude and category scales: (1) ratio judgments on a transformed category scale, (2) interval judgments, and (3) hybrid judgments. The last term refers to

the tentative explanation that magnitude judgments are a cross between pure ratio and interval judgments.

Krantz, D.H. A THEORY OF MAGNITUDE ESTIMATION AND  
1972 CROSS-MODALITY MATCHING. *J. math. Psychol.*, 9,  
168-99.

The generalizations that have emerged from "ratio scaling" of sensory continua include: consistency among various methods, consistency with changes in modulus, and the power law. These generalizations pose difficulties for the commonly held view (called here *mapping theory*) that "ratio scaling" judgments are mediated by mappings of stimuli into sensations. The main difficulty is that the ratio-like consistency properties of cross-modality matching cannot be accounted for by essentially nonnumerical sensations, and hence must be treated by a process theory which assumes that cross-modality matching is mediated by magnitude estimation. An alternative process theory (*relation theory*) assumes that "ratio scaling" judgments are not mediated by a property of single stimuli (sensation) but rather by a property of pairs of stimuli. The perceived relations of pairs (called sensation "ratios") are assumed to share a qualitative property of numerical ratios. This axiom leads to a measurement representation by ratios of psychophysical functions (sensation functions). These psychophysical functions can be obtained directly by magnitude estimation provided that mental estimation of length ratios and perceived sensation "ratios" of length pairs are ordered alike (in fact, both correspond roughly to physical length ratios). The assumed ordering of stimulus pairs by sensation "ratios" leads to a simple account of the various empirical consistency generalizations. Such an ordering may also be related to other pair orderings, such as those based on discriminability measures and on perceived sensation "differences."

Levison, M. and Restle, F. INVALID RESULTS FROM THE METHOD  
1968 OF CONSTANT STIMULI. *Perception Psychophys.*, 4,  
121-22.

The method of constant stimuli was shown to produce constant errors in the direction expected by E. In an experiment, 89 subjects compared variable lines with a standard, each S producing a psychometric function and point of subjective equality (PSE). Four groups differed in the particular range of variable stimuli used; whether the stimuli averaged longer or shorter than the standard and the mean of the variables, as predicted by adaptation level theory. In many experiments the set of variables is chosen on the basis of theory or pilot studies; the present study shows that PSE will be spuriously drawn toward the center of the variables, hence toward E's pre-experimental expectations.

Levitt, H. TESTING FOR SEQUENTIAL DEPENDENCIES. *J. 1967 Acoustic Soc. Amer.*, 43(1), 65-9.

Certain psychophysical procedures assume that successive responses are statistically independent. A method for testing the validity of this assumption using the up-down procedure is described. Two identical up-down strategies are interleaved according to a rule designed to produce a large difference between the resulting estimates should a sequential dependency exist. The null hypothesis that no dependency exists is postulated, and the two estimates are compared for differences significantly larger than could have occurred by chance. The experiment reported here was designed to test the possibility that responses of the same type are more likely to follow in sequence than would occur with statistically independent judgments. The masked threshold for a 250-Hz tone in wide-band noise was measured for five subjects on three separate occasions. Two of the five subjects showed a small but consistent difference between the two concurrent estimates, indicating a slight tendency for like responses to follow in sequence. The technique of interleaving by rule may also be of value in measuring hysteresis effects and in detection-theory experiments, where it may be possible to discriminate between sequential effects influencing the subject's sensitivity and those affecting the subject's choice of criterion.

Luce, R.D. ON THE POSSIBLE PSYCHOPHYSICAL LAWS. *Psychol. Rev.*, 66(2), 81-95.

The following problem was considered. What are the possible forms of a substantive theory that relates a dependent variable in a continuous manner to an independent variable? Each variable is idealized as a numerical continuum and is restricted by its measurement theory to being either a ratio, an interval, or a logarithmic interval scale. As a principle of theory construction, it is suggested that transformations of the independent variable that are admissible under its measurement theory shall not result in inadmissible transformations of the dependent variable (consistency) and that the form of the functional relation between the two variables shall not be altered by admissible transformation of the independent variable (invariance). This principle limits significantly the possible laws relating the two continua. These results do not hold in two important circumstances. First, if the independent variable is a ratio scale that is rendered dimensionless by multiplying it by a constant having units reciprocal to those of the independent variable, then either the principle has no content or it is violated, depending upon how one wishes to look at the matter. Second, if the variables are discrete rather than continuous, or if the functional relation is discontinuous, then laws other than those given in this article are possible.

Menger, K. MENSURATION AND OTHER MATHEMATICAL CON-  
1959 NECTIONS OF OBSERVABLE MATERIAL. In C.W. Churchman and P. Ratoosh, *Measurement: Definitions and Theories*, New York: John Wiley and Sons.

Miller, G.A. THE MAGICAL NUMBER SEVEN, PLUS OR MINUS  
1966 TWO: SOME LIMITS ON OUR CAPACITY FOR PROCESS-  
ING INFORMATION. *Psychol. Rev.*, 63(2), 81-97.

Morrison, H.W. TESTABLE CONDITIONS FOR TRIALS OF  
1963 PAIRED COMPARISON CHOICES. *Psychometrika*, 28(4),  
369-90.

Munson, W.A. ISOPREFERENCE METHOD FOR EVALUATING  
1962 SPEECH-TRANSMISSION CIRCUITS. *J. Acoustic Soc.  
Amer.*, 34(6), 762-74.

This exploratory paper describes a modification of the paired comparison technique for deriving a one-dimensional scale for rating speech transmissions systems on the basis of listener preferences. The numbers on the scale, which run from 0 to 100, are called "Transmission Preference Units" (TPU) and are intended to be used to evaluate any speech transmission system, regardless of the noise or distortion encountered, provided the system is less preferred than the reference condition, namely, real speech at 1 m. If the TPU ratings for two transmission systems are known, it is believed that the difference can be used to predict the percentage of users who would prefer the system with the higher rating. Subjective listening experiments have been conducted with a small group averaging seven observers for rating a large number of speech transmission conditions on the TPU scale. Equal preference contours were determined on speech level-noise level planes for several different frequency bands. The listening tests require only simple A-B preference comparisons of two brief samples of speech heard consecutively. The data suggest that the basic requirement of transitivity essential for a simple useful one-dimensional rating scale may be satisfied for many types of transmission conditions. Thus if transmission condition A is judged to equal condition B in preference, and condition B equals C, then A and C were also found to be judged equal. This apparently holds even though A, B, and C are circuits differing widely in their physical parameters. This study is reported at this stage in the hope that other laboratories may become interested in checking and extending the limited scope of the work reported here. Such confirmation is necessary before a simple one-dimensional TPU scale can be postulated and used with confidence for precise evaluations. For the purposes of this work, two circuits are considered to be equal in preference when half of the judgments of the group favor one and half favor the other circuit; it does not follow that individual observers are indifferent in their preferences for the two circuits.

**Parducci, A. and Perrett, L.F. CATEGORY RATING SCALES: EFFECTS OF RELATIVE SPACING AND FREQUENCY OF STIMULUS VALUES. *J. Experimental Psychol.* 89(2), 427-52. Monograph.**

The context for judgment was studied by manipulating the frequency distribution of the sizes of squares presented in different sets. The resulting shifts in absolute category ratings are largely accounted for by a simplified range-frequency model. This model assumes that the rating scale locates stimuli with respect to the end points and that there is also a tendency to use different parts of the scale with equal frequency. As implied by the model, a trading relationship was demonstrated between the effects of varying the relative spacing and frequency of the stimulus values. Thurstone scaling was stable across sets, except that discriminability improved when the range was narrowed, especially near the new end points. Neither Thurstone nor rating scales were affected by the number of categories. Implications were drawn for inferring the utility of future outcomes from ratings obtained in the special contexts in which decisions are made.

**Poulton, E.C. THE NEW PSYCHOPHYSICS: SIX MODELS FOR MAGNITUDE ESTIMATION. *Psychol. Bulletin*, 69(1), 1-19.**

Six pictorial models describe the effect upon magnitude estimation of the choices of values of independent variables: (a) the range of stimuli, (b) whether the range includes the threshold region, (c) the position of the standard (1st stimulus) within the range, (d) the distance of the 1st variable (2nd stimulus) from the standard, (e) whether the set of numbers used is infinite or finite, and (f) the size of the modulus (the number given to its standard). The range of stimuli (a) alone accounts for about 1/3 of the variance in S.S. Stevens' table of exponents. Effects are classified under headings of response bias, level of adaptation, and a mathematical artifact. They are more compatible with a learned-calibration theory than with a simple transducer theory, but neurophysiological data are too varied to decide between the two types of theory. Transfer effects within and between experiments are described. The approximately logarithmic relationship usually

found between partition or category scales and magnitude scales can be explained in terms of (b) and (e). The exact form also depends on experimental design and history of the observers, and these points need more attention both in executing and reporting experiments.

**Prokasy, W.F. and Hall, J.F. PRIMARY STIMULUS GENERALIZATION. 1963** *Psychol. Rev.*, 70(4), 310-22.

The purpose of this paper was to examine the widely held assumption that there is an empirically based need for a construct of "stimulus generalization." This was done by (a) outlining its historical evolution, (b) discussing its role as a label in secondary sources, and (c) evaluating methods employed in measuring it. It was pointed out that the construct is based upon some specious premises of early behaviorism, and that the way the label itself is employed assumes a unique process and that the empirical operations for measuring it differ little from those employed in discrimination learning. It was concluded that, while the methods of measuring stimulus generalization might help to define percepts, the assumption of a special process under that label contributes little to our knowledge of behavior.

**Ross, J. and Di Lollo, V. JUDGMENT AND RESPONSE IN MAGNITUDE ESTIMATION. 1971** *Psychol. Review*, 78, 515-27.

Context is shown to influence not only judgment but, independently, response in the task of magnitude estimation. Pure response effects are isolated and characterized in several studies employing a common shift design and are contrasted with judgmental effects. Response scales in magnitude estimation are presented as interval scales constructed from a direct comparison of stimulus differences and shown then to account for context effects. Implications for psychophysical theory are considered.

**Rule, S.J. EFFECT OF INSTRUCTIONAL SET ON RESPONSES TO COMPLEX SOUNDS. 1964** *J. Exper. Psychol.*, 67(3), 215-20.

Ninety subjects rated sounds under loudness, noisiness, or annoyance instructions. The sounds were composed of a ran-

dom noise with discrete tone components. Four factors of sound were investigated: (a) overall intensity, (b) fundamental tone frequency, (c) fundamental tone intensity, and (d) overtone intensity. An analysis of the interactions between instructions and stimulus factors indicated that instructions set subjects to give different emphasis to stimulus factors. Overall intensity was emphasized most under loudness instructions, followed by noisiness and annoyance instructions. Fundamental tone frequency and fundamental tone intensity were given greatest emphasis under annoyance instructions, followed by noisiness and loudness instructions. No difference was found for overtone intensity.

Sorkin, R.D. EXTENSION OF THE THEORY OF SIGNAL DETECTABILITY TO MATCHING PROCEDURES IN PSYCHOPHYSICS. *J. Acoustic Soc. Amer.*, 34(11), 1745-51.

The theory of signal detectability is used to analyze experiments where the observer's task is to state, after two signal presentations, whether the signals were the same or different. A model is suggested for predicting human performance in auditory "matching" tasks using data from detection and discrimination experiments. Three experiments are discussed which lend support to the model's application. The first, a two-alternative forced-choice, pulsed-carrier experiment, serves to determine each observer's efficiency. The efficiency is assumed constant provided certain observation interval and signal characteristics are held fixed, as they were during the entire experimental sequence. The second was a simple matching task, where the first observation interval always contained a specified signal and the second sometimes contained a signal identical to the first. In the third experiment the signal appearing in the first interval was randomly chosen from a set of possible signals, thus removing the long-term memory requirement and necessitating a comparison observation based on both intervals. The results are consistent with the assumption of constant efficiency across different tasks, and close agreement with the model's predictions for matching performance is demonstrated. Also discussed are some interesting side issues raised by the experimental data which are relevant to current use of the matching procedure in



other areas of psychology. Consideration is made of possible further applications of the matching procedure, such as in determining the value of  $\sigma$  in recognition experiments.

**Stevens, J.C. and Marks, L.E. CROSS-MODALITY MATCHING OF BRIGHTNESS AND LOUDNESS. Proceedings of the National Academy of Science, 54, 407-11.**

In several experiments, observers have undertaken to match for apparent intensity the sensations aroused in two different sense modalities. Despite the uncertainty sometimes expressed about what constitutes equal apparent magnitude in the face of a qualitative disparity (like the well-known difficulty of heterochromatic photometry), the method of cross-modality matching has demonstrated that subjective magnitude grows as a power function of stimulus intensity. The present study undertakes a cross-modality comparison of brightness and loudness—probably the two most important continua having to do with sensory intensity. The form of the equal-sensation function obtained from a series of cross-modality matches can be tested against predictions of the psychophysical law proposed by S.S. Stevens, which states that the subjective magnitude grows as a power function of the stimulus magnitude. The present study used the method of cross-modality matching in order to determine whether brightness and loudness would produce an equal-sensation function whose exponent is the ratio of the exponents previously determined for these two sense modalities.

**Stevens, S.S. ISSUES IN PSYCHOPHYSICAL MEASUREMENT. 1971 *Psychol Rev.*, 78, 426-50.**

Two classes of ratio-scaling procedures are outlined—magnitude matching and ratio matching—and their assets and liabilities are noted. Partition-scaling procedures, which are supposedly designed for interval scaling, produce results that can be described by a power function with a virtual or “as if” exponent. Since the virtual exponent is smaller than the actual exponent of the continuum, the category scale is nonlinear. The virtual exponent provides a convenient descriptor of several kinds of partition operations. Other topics dis-

cussed include individual differences among subjects' exponents, procedures of averaging, and the effects of stimulus range on exponents. It is suggested that the power law asserts a nomothetic imperative.

Stevens, S.S. MEASUREMENT, STATISTICS, AND THE SCHEMA-1968 PIRIC VIEW. *Science*, 161, 849-56.

Stevens, S.S. A METRIC FOR THE SOCIAL CONSENSUS. *Science*, 1966 151,(4), 530-41.

What are the invariances in the manifold experiments involving human judgment? A convergence of evidence from fields as disparate as psychophysics and criminology has pointed to stable and constant relations. One such relation states that subjective magnitude is a power function of stimulus magnitude. The underlying invariance then becomes the simple principle that equal stimulus ratios produce equal subjective ratios. On many of the continua discussed, the stimuli can be measured only on a nominal scale, for the stimuli are verbal statements, occupations, crimes, musical selections, and other nonmetric items. On those continua the power law cannot be confirmed directly, but there emerges another notable invariance. For both kinds of continua, those based on metric stimuli and those based on nonmetric stimuli, there is a constant relation between the scale erected by direct judgment and the scale derived from a unitizing of variability or confusion. Whether the stimuli are measurable on ratio scales or only on nominal scales, the judgmental scale based on units of variability is approximately proportional to the logarithm of the scale so constructed by one or another of the direct scaling methods. The extensive invariance of this logarithmic relation attests to a principle known throughout all of science—namely, that error or variability tends to be "relative": The size of the error grows with magnitude. The principle finds expression under many phrasings: The standard deviation increases the mean, the coefficient of variation remains constant; the signal-to-noise ratio stays put; accuracies can be stated as one part in so many. The emergence of a similar canon in the subjective domain suggests an essential unity among the principles that govern quantitative relations in

widely diverse endeavors. For those who must build their science on one or another consensus of human judgment, a way seems open for an effective quantification.

**Stevens, S.S. ADAPTATION LEVEL VERSUS THE RELATIVITY  
1958 OF JUDGMENT. *Amer. J. Psychol.*, 71, 633-46.**

**Stevens, S.S. and Galanter, E.H. RATIO SCALES AND CATEGORY  
1957 SCALES FOR A DOZEN PERCEPTUAL CONTINUA. *J. Exper. Psychol.*, 54(6), 377-411.**

Ratio scales of subjective magnitude are compared with category rating-scales on several judgmental continua. These continua divide themselves into two classes. Class I (prothetic) continua are those on which the category scale is nonlinear relative to the magnitude scale. Examples are apparent length, duration, numerosness, area, weight, loudness, brightness and lightness. On each of these continua the ratio scale of subjective magnitude approximates a power function of the physical stimulus. The category scale however, is concave downward relative to the ratio scale, principally because discrimination is relatively better at one end of the continuum than at the other. In general, the category scale is less curved than logarithmic. On Class II (metathetic) continua the category scale "may be" linearly related to the magnitude scale. Examples are visual position, inclination, pitch and proportion. On these continua discrimination (expressed in subjective units) tends to be constant over the range, although landmarks and differential familiarity may introduce non-uniformities. On both types of continua the form of the category scale depends on the relative spacing of the stimuli and on the relative frequency of their presentation. By means of an iterative procedure, the effects of spacing and frequency can be neutralized and the "pure" form of the category scale obtained. The form of the category scale is generally independent of the number of categories employed, and, except under special circumstances, it is independent of the range and number of stimuli used. Unlike the category scale, the ratio scale of subjective magnitude is relatively unaffected by stimulus spacing. Although on metathetic continua "equal

appearing intervals" may be equal, on prothetic continua such intervals are not equal in terms of scales of subjective magnitude.

Stevens, S.S. and Greenbaum, H.B. REGRESSION EFFECT IN  
1966 PSYCHOPHYSICAL JUDGMENT. *Perception and Psychophys.*, 1, 439-46.

Stewart, J.L. QUANTITATIVE LAWS FOR SENSORY PERCEPTION.  
1963 *Psychol. Rev.*, 70(2), 180-92.

A model for subjective intensity derived from an elementary sensor provides linear filtering, rectification with variable power law exponent, and finite time averaging. The model is consistent with the physiological measure of average neural pulse rate. Simplified mathematical representations are employed to explain partial and complete masking. The Stevens law and a modified Weber law are derived as special cases. When extended to an array of sensors, a broadly significant pattern theory for recognition results which explains diplacusis and other phenomena. Direct electronic stimulation may be achieved (and has) so as to yield solutions to problems which are too complex to be analyzed in other ways.

Swets, J.A. IS THERE A SENSORY THRESHOLD? *Science*, 134,  
1961 168-77.

We have the possibility of a threshold, but it is no more than a possibility, and we must observe that since it is practically unmeasurable it will not be a very useful concept in experimental practice. Moreover, even if the low threshold proposed by Tanner, Birdsall, and Swets did exist, and were measurable, it would not restrict the application of detection theory. We may note that yes-no data resulting from a supra-threshold criterion depend upon the criterion but are completely independent of the threshold value. The same limitation applies to the quantal threshold. It appears that a compelling demonstration of this concept will be difficult to achieve, so that in practice a theory and a method that deal with noise will be required. In measuring sensitivity it is desirable to manipulate the response criterion so that it lies in a

range where it can be measured, to include enough catch trials to obtain a good estimate of this response criterion, and to use a method of analysis that yields independent measures of sensitivity and the response criterion. One qualification should be added: We can forego estimating the response criterion in a forced-choice experiment. Under the forced-choice procedure, few observers show a bias in their responses large enough to affect the sensitivity index appreciably. Those who show such a bias initially can overcome it with little difficulty. As a result, the observer can be viewed as choosing the interval most likely to contain a signal, without regard to any criterion. For this reason, the forced-choice procedure may be used to advantage in studies having an emphasis on sensory processes, rather than on motivational or response processes..

Taylor, M.M. COMMENTS ON "SENSORY THRESHOLDS AND  
1964 RESPONSE BIAS." *J. Acoustic Soc. Amer.*, 36(3), 599-600.

Taylor, M.M. and Creelman, C.D. P.E.S.T.: EFFICIENT ESTI-  
1967 MATES ON PROBABILITY FUNCTIONS. *J. Amer. Acous-  
tic Soc.*, 41, 782-87.

An adaptive procedure for rapid and efficient psychophysical testing is described. PEST (Parameter Estimation by Sequential Testing) was designed with maximally efficient trial-by-trial sequential decisions at each stimulus level, in a sequence which tends to converge on a selected target level. An appendix introduces an approach to measuring test efficiency as applied to psychophysical testing problems..

Teghtsoonian, M. THE JUDGMENT OF SIZE. *Amer. J. Psychol.*,  
1968 81(4), 392-402.

Judged size, scaled by the method of magnitude-estimation, is related to physical size by a power function. The exponent of the power function may take a value of 1.0—that is, judged size may be in direct correspondence to physical size—only under special circumstances: (1) for judgments of linear dimensions, and (2) when area-ratios can be successfully determined on the basis of judgments of length and physical

area is estimated. When  $O$  is asked to judge the apparent size of two- and three-dimensional figures, the exponent of the power function is appreciably less than unity. For two-dimensional figures, this value is about 0.8, and for three-dimensional figures, it is about 0.7. Neither value appears to be greatly influenced by the form of the figures studied.

**Teghtsoonian, R. ON THE EXPONENTS IN STEVENS' LAW AND**  
**1971 THE CONSTANT IN EKMAN'S LAW. *Psychol. Review*, 78,**  
**71-80.**

It follows from Stevens' psychophysical power law,  $\psi = a\phi^n$ , that the exponent  $n = \log R_\psi / \log R_\phi$ , where  $R_\phi$  is the ratio of the greatest to the least stimulus intensity and  $R_\psi$  is the ratio of corresponding sensory magnitudes. Data from 21 experiments by S.S. Stevens show a correlation (Pearson  $r$ ) of .935 between  $\log R_\phi$  and  $1/n$ , implying that  $\log R_\phi$  is nearly constant. On this basis it is proposed that a single scale of sensory magnitude serves a wide variety of perceptual continua, and that variation in power law exponents is primarily due to variation in dynamic ranges. The hypothesis that there is just one scale of sensory magnitude suggests that there may be just one value for subjective resolving power. When Weber fractions are transformed to their subjective counterparts by the psychophysical power law, the result for nine different continua is nearly constant at about .03.

**Tempone, V.J. THE NATURE OF THE STIMULUS IN PRIMARY**  
**1968 STIMULUS GENERALIZATION. *Canadian J. Psychol.*,**  
**22(4), 244-51.**

In the stimulus generalization literature little attention has been given to the nature of the stimulus. It has been assumed that  $E$ 's definition of the training stimulus is isomorphic with  $S$ 's perception of it. It was hypothesized that  $S$  may make a discriminative response to a stimulus, but the discriminative stimulus might differ depending upon the  $S^\wedge$ . Children were reinforced for responding to an  $S^D$  (a ten inch black square) and not reinforced for responding to an  $S^\wedge$ . In the first two conditions the  $S^\wedge$  lacked form or contour. In the remaining two conditions the  $S^\wedge$  contained contour. Here, the  $S^\wedge$  was a

nine inch black equilateral triangle or a four inch light gray square. Following discrimination training, subjects were presented with generalization stimuli that varied along a size dimension from the  $S^D$ .

Thurstone, L.L. A LAW OF COMPARATIVE JUDGMENT. *Psychol. Rev.*, 34, 273-86.

Torgerson, W.S. QUANTITATIVE JUDGMENT SCALES. In H. Guilksen and S. Messick (Eds.), *Psychological Scaling: Theory and Application*. New York: John Wiley and Sons, 21-31.

Wald, A. SEQUENTIAL ANALYSIS. New York: John Wiley and Sons, pp. 88-105 and 196-99.

Warren, R.M. A BASIS FOR JUDGMENTS OF SENSORY INTENSITY. *Amer. J. Psychol.*, 71, 675-87.

The physical-correlate theory is proposed as the basis for judgments of sensory intensity. The theory holds that estimates of sensory magnitude are based upon experiences with the manner in which sensory excitation is correlated with the quantity of some physical attribute associated with the stimulus. The theory is supported by experimental data for half-subjective-intensity judgments of heaviness, the four tastes, brightness, loudness, and pitch. For judgments involving half-subjective heaviness and half-taste sensation, the physical-correlate theory reduces to the rule that judgments of sensory intensity are equivalent to estimates of stimulus-magnitude. Thus, for heaviness, experiences with relative physical weight, and for taste, experiences with relative concentration obtained by adding various amounts of solutes and of diluting sapid solutions with water provide the basis for judgment. With other sensations, however, individuals are not familiar with the physical scale describing stimulus strength and the physical correlates appear to be as follows: for brightness—the manner in which stimulation varies with the distance from the illuminated object to its light source; for loudness—the manner in which stimulation varies with the distance of the listener from the sound source; for pitch—the octave-relation of the musical scale.

Wherry, R.J. ORDERS FOR THE PRESENTATION OF PAIRS IN  
1938 THE METHOD OF PAIRED COMPARISONS. *J. Exper.*  
*Psychol.*, 23, 651-60.

Yilmaz, H. PERCEPTUAL INVARIANCE AND THE PSYCHO-  
PHYSICAL LAW. *Perception and Psychophysics*, 2, 533-38.



### Chapter III

#### PERCEPTION, MODELING TECHNIQUES

The study of perception in the human environment has been enriched by contributions from many disciplines. In this section, we have included examples of works illustrating various approaches to problems of perception and evaluation.

The psychology of art and aesthetics are important considerations in any study of user evaluation of environments. In the same vein, studies of aesthetic psychology must be understood in the light of cultural variations in visual perception, and of learned norms and biases in evaluation.

We have included some of the classic works describing the main philosophies developed in the Western world, such as works by Arnheim, Croce, Jung, and Kohler, among others. We have also included examples of recent experimental research in the areas of perception and aesthetic response.

Because of their importance to the proper understanding of the mechanisms of perception, we have included selected references dealing with the physiology of the eye and with brain mechanisms related to visual perception.

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Much of the empirical research in the above areas is facilitated by the use of models or simulated environments for testing perceptual responses. A scale model of either an interior or exterior of a building or of any of its parts may easily include numerous alternatives for testing purposes, a possibility that is very difficult and costly to achieve in real environments. We have therefore included in this section some references on modeling techniques, and on studies utilizing models in their experiments. A comprehensive source on model techniques listed in this section is *Architectural and Interior Models, Design and Construction* (Hohaus, 1970).

### PERCEPTION, MODELING TECHNIQUES

Anonymous. STUDIES OF HUMAN VIGILANCE-AN OMNIBUS  
1968 OF TECHNICAL REPORTS. Human Factors, Inc.: Santa  
Barbara Research Park, Goleta, Calif.

Arnheim, R. ART AND VISUAL PERCEPTION. Berkeley and Los  
1971 Angeles: University of California Press.

Arnheim, R. TOWARD A PSYCHOLOGY OF ART. Berkeley, Calif.:  
1972 University of California Press.

Arnheim, R. VISUAL THINKING. Berkeley, Calif.: University of  
1972 California Press.

Aschenbrenner, K. and Isenberg, A. AESTHETIC THEORIES. Engle-  
1965 wood Cliffs, N. J.: Prentice-Hall.

Bachelard, G. THE POETICS OF SPACE. Boston: Beacon Press.  
1969

Berleant, A. THE AESTHETIC FIELD. Springfield, Ill.: Charles C.  
1970 Thomas.

Berlyne, D.E. AESTHETICS AND PSYCHOBIOLOGY. New York:  
1971 Appleton-Century Crofts.

**Berlyne, D.E. NOVELTY, COMPLEXITY, AND HEDONIC VALUE.**  
1970 *Perception and Psychophysics* 8(5A), 279-86.

Two experiments, in which subjects were exposed to sequences of colored shapes, investigated effects on ratings of "pleasingness" and "interestingness" of variables that had previously been shown to affect ratings of "novelty." The results indicate, on the whole, that both pleasingness and interestingness increase with novelty. These findings run counter to those of experiments indicating an inverse relation between novelty and verbally expressed preferences. Two further experiments examined effects of some variables that might account for this apparent discrepancy. Homogeneous sequences declined in judged "pleasantness" more than sequences in which several stimuli were interspersed, and simple stimuli became less pleasant as they became less novel, while complex stimuli declined less or became more pleasant. The findings are related to hypotheses regarding mechanisms of hedonic value.

**Blaut, J.M. and Stea, D. PLACE LEARNING.** Worcester, Mass.:  
1969 Clark University, Place Perception Center, Research Report No. 4.

**Blaut, J.M., McCleary, G.F., Jr. and Blaut, A.S. ENVIRONMENTAL**  
1970 **MAPPING IN YOUNG CHILDREN.** *Environment and Behavior* 2(3), 335-49.

One component of environmental behavior is environmental mapping, the activity by which macro-environmental information is transformed into a cognitive map (Tolman, 1948). This study uncovers sophisticated mapping abilities in young children. The findings seem to have both theoretical and practical significance. On the one hand, they suggest that environmental mapping is a very primitive form of behavior, and they lead us to a developmental model for such behavior. On the other hand, they suggest some new approaches to environmental education.

**Blumer, H. SYMBOLIC INTERACTIONISM.** Englewood Cliffs, N.J.:  
1969 Prentice-Hall.

Bruner, J. ON PERCEPTUAL READINESS. *Psychological Review*, 1957 64, 123-52.

This paper considers a general view of perception that depends upon the construction of a set of organized categories in terms of which stimulus inputs may be sorted, identified, and given connotative meaning. It also explores perceptual readiness, that is, the relative accessibility of categories to stimulus inputs. The more accessible a category, the less the stimulus input required for it to be sorted in terms of the category, given a degree of match between the characteristics of the input and the specifications of the category. There appear to be two general determinants of category accessibility. One of them is the likelihood of occurrence of events learned by the person in dealing with the world of objects and events. One can think of this activity as achieving a minimization of surprise for the organism. A second determinant of accessibility is the requirements of search dictated by the need to carry out habitual enterprises such as walking, reading, or whatever it is that makes up the round of daily, habitual life. Finally, the article considers some of the ways in which failure of perceptual readiness comes about—first, through a failure to learn appropriate categories for sorting the environment and for following its sequences, and second, through a process of interference whereby more accessible categories with wide acceptance limits serve to mask or prevent the use of less accessible categories for the coding of stimulus inputs.

Bruner, J.S. and Postman, L. ON THE PERCEPTION OF INCONGRUITY: A PARADIGM. *Journal of Personality* 18, 206-23.

This work reaffirms that perceptual organization is powerfully determined by expectations built upon past commerce with the environment. When such expectations are violated by the environment, the perceiver's behavior can be described as resistance to the recognition of the unexpected or incongruous. Implementing this resistance are (1) the dominance of one principle of organization which prevents the appearance of incongruity and (2) a form of "partial assimilation to expectancy" which we have called compromise. When these responses fail and when correct recognition does not occur,

what results may best be described as perceptual disruption. Correct recognition itself results when inappropriate expectancies are discarded after failure of confirmation.

Butler, A.J. MODEL DESIGN TECHNIQUES. *J. Inst. Heating Vent.* 1964 *Engrs.* 31, 401-406.

Three-dimensional models may prove to be effective supplements to the two-dimensional methods. The chemical engineering industry now uses models extensively for the design of plants costing more than 70,000. Models and photographs are often used instead of general arrangement drawings for the initial layout of plant and for the detailed design of pipework. Chemical engineers say that these new techniques have been especially important in reducing design and construction time. They also claim that better designs result from a clearer visualization and assessment of both problem and solution, that communications are improved as designers and others associated with the project are drawn together around the model, that maintenance and construction requirements can be more readily foreseen, and that tender prices are lower because tendering parties learn that there are usually fewer last minute changes when a model has been used. The article is based on practical experience in the application of model techniques to actual design problems. Simple, inexpensive techniques that can be used in any heating and ventilating design office are described.

Choungourian, A. COLOR PREFERENCES: A CROSS-CULTURAL 1969 AND CROSS-SECTIONAL STUDY. *Perceptual and Motor Skills* 28(8), 801-2.

Cohen, J. PSYCHOLOGICAL TIME. *Scientific American*, November 1964 1964, 116-24.

This experiment explores how much circumstances affect the subjective sense of the passage of time.

Coleman, F. CONTEMPORARY STUDIES IN AESTHETICS. New 1968 York: McGraw Hill.

Conner, A.K. MODELS AS AN AID IN THE ACOUSTICAL DESIGN OF AUDITORIUMS. *Acustica* 9, 403-407.

Cornsweet, T. VISUAL PERCEPTION. New York: Academic Press. 1970

Coughlin, R.E. and Goldstein, K.A. THE EXTENT OF AGREEMENT AMONG OBSERVERS ON ENVIRONMENTAL ATTRACTIVENESS. Regional Science Research Institute, Discussion Paper Series: No. 37.

Cowan, H.J., Gero, J.S. and Ding, G.D. MODELS IN ARCHITECTURE. American Elsevier Publ. Co.

Craik, K.H. ENVIRONMENTAL PSYCHOLOGY. In K.H. Craik, et al. *New Directions in Psychology* 4. New York: Holt, Rinehart and Winston.

Craik, K.H. THE COMPREHENSION OF THE EVERYDAY PHYSICAL ENVIRONMENT. *J. American Institute of Planners* 34(1A), 29-37.

How do people come to grasp cognitively the everyday physical world in which they live and move? What terms do they employ in talking about it? What aspects of it do they distinguish and attend to? What expectations do they bring to it? What influences the way an individual comprehends his physical surroundings? These are surely some of the questions to which the environmental psychologist would be expected to turn his attention. How would he proceed in exploring these questions? The research strategy begins with defining the terms of discourse, identifying the elements of the problem, and studying their interrelationships. Out of this basic procedure, terminology is introduced, methods are developed, research projects are conceived, and some by-products of practical interest to the design and planning professions emerge.

Croce, B. AESTHETIC. New York: Noonday Press (Trans. by Douglas Ainslie).

**Davids, A. GENERALITY AND CONSISTENCY OF RELATIONS  
 1955 BETWEEN THE ALIENATION SYNDROME AND COGNITIVE PROCESSES. *J. Abnorm. Soc. Psychol.* 51(61).**

Twenty male undergraduates were administered an auditory projective technique, a word association technique, and a sentence completion technique. They also engaged in two personal interviews with a clinical psychologist. Each of these procedures was designed to provide an independent measure of the subjects' relative standing on the alienation syndrome, which consists of relatively high scores in egocentricity, distrust, pessimism, anxiety and resentment, and relatively low scores in sociocentricity, trust, and optimism. The experimental findings demonstrated that when the subjects listened to a recorded series of incoherent spoken passages, constructed by intermingling words and statements representative of these traits and attitudes, their personalities were likely to influence selective retention and perception. Individuals who were judged clinically to be high on the syndrome of alienation were found to be sensitized to the words and statements indicative of alienation, and tended to selectively remember this material as measured by the methods of immediate recall, delayed recall, and recognition. Turning to other cognitive tasks, it was found that readiness of association and type of reaction to the word association and sentence completion techniques could be predicted on the basis of selective auditory memories. These overall findings of general and consistent relations between motivation and cognitive processes were interpreted as favorable evidence for the development of a general theory of cognition. Finally, it was pointed out that the present results are in keeping with the theory underlying projective techniques, and relations between clinical application and controlled research were discussed.

**Ding, G.D. MODELS IN THE DESIGN OF BUILDINGS. *Arch. Sci.*  
 1964 *Rev.* 7, 48-54.**

Model methods are widely used to gain useful information about a prototype without the expense of first constructing the prototype itself. The information sought may be either confirmatory or exploratory. If exploratory, model studies



may be the only means available to the designer. This article presents two sets of mathematical formulas, the first set establishing the degree of similitude between the prototype and the model, and the second set stating the pertinent variables in building design in terms of classical dimensional analysis, that is, how to represent the significant variables (aesthetic, functional planning, town planning, construction, structural, thermal, acoustical and lighting). Models vary according to which variables are emphasized; the need for selection of the appropriate model is stressed and illustrated.

**Dubos, R. MAN ADAPTING.** New Haven: Yale University Press.  
1967

**Ehrenzweig, A. THE HIDDEN ORDER OF ART.** Berkeley, Calif.:  
1971 University of Calif. Press.

**Fader, L. and Leonard, C. HOLOGRAPHY: A DESIGN PROCESS**  
1971 *AID. Progressive Architecture*, 92-94.

Traditional architectural graphic modes and symbols are usually confusing, since few of the symbols are universally accepted, and only a select group of individuals is educated in the graphic language. Models are also difficult to accept as authentic simulations, since true scale is upset by the relationship of the models to larger items surrounding it, such as people, pencils and desks. Further, it takes time to understand a model. In walking from one side to another, one often loses his visualization of the first view. Holography offers a three-dimensional representation of form that can be accented with textural gradients, plus showing the sequence of construction on a single photographic plate. The project described in this article not only produced the desired sequence, but also, by rapidly rotating the hologram from one image to the next, allowed the observer to see a three-dimensional form being built on top of the previous one. In this application, the building organization, volume, space allocation, form and material are quickly revealed. Other applications could allow changes in form over time to be modeled with a greater degree of completeness.

**Fisher, G.H. THE FRAMEWORKS FOR PERCEPTUAL LOCAL-  
1968 IZATION.** University of Newcastle-on-Tyne, Department of  
Psychology.

**Gardner, W.R., Hake, H.W. and Eriksen, C.W. OPERATIONALISM  
1956 AND THE CONCEPT OF PERCEPTION.** *Psychol. Rev.* 63,  
149-59.

Perception is conceived as a process intervening between stimuli and responses. As such it can be viewed as a concept whose properties may be delimited by converging operations. Converging operations are any set of experimental operations which eliminate alternative hypotheses and which can lead to a concept which is not uniquely identified with any one of the original operations, but is defined by the results of all operations performed. Thus converging operations can lead to concepts of processes which are not directly observable. For example, converging operations can be used to describe properties of perceptions which are distinct from those of the response system directly observed. Illustrations from current experimental problems in perception indicate how some response characteristics may be isolated from perceptual properties, and vice versa. Some of these properties have been ascribed to perception without supporting converging operations by researchers dissatisfied by the sterility of operationism as it is commonly, but mistakenly, conceived.

**Gibson, J.J. THE PERCEPTION OF THE VISUAL WORLD.** Boston:  
1950 Houghton, Mifflin.

**Gombrich, E.H. ART AND ILLUSION.** Princeton, N. J.: Princeton  
1972 University Press, Bollingen Series.

**Gombrich, E.H. THE VISUAL IMAGE.** *Scientific American* 227(3),  
1972 82-98.

**Gregory, R.L. THE INTELLIGENT EYE.** New York: McGraw-Hill.  
1971

**Gregory, R.L. EYE AND BRAIN, THE PSYCHOLOGY OF SEEING.**  
1967 New York: McGraw Hill.

Haldane, J. PSYCHOPHYSICAL SYNTHESIS OF ENVIRON-  
1966 MENTAL SYSTEMS. Berkeley, Calif.: California Book Co.

Heath, T.F. PROBLEMS OF MEASUREMENT IN ENVIRONMENT-  
1968 AL AESTHETICS. *Architectural Science Review* 1, 17-28.

The present state of aesthetic studies resembles that of the research work of the chemist who, after some years labour, was able to report that he had discovered a substance which was colourless, odourless, tasteless, and useless. Nothing is clearly established, no chain of cause and effect, no quantitative relationship which could be of the slightest assistance to anyone. There are a large number of theories, mostly wordy, confusing, and serving to rebut past philosophical opinion than to unify the considerable but scattered body of factual data now becoming available. The subject urgently needs a staunchly empirical approach and a determination to develop methods which can be applied to practical difficulties. It is for this reason that this paper concentrates on methods of measurement, for if we can solve the problems of measurement, sound theory and practical applications will follow.

Heerman, C. LIGHT IN THE HUMAN ENVIRONMENT AS THE  
1970 ARTIST SEES IT. Los Angeles: Sunbeam Lighting Co.

Henle, M. (Ed.) DOCUMENTS OF GESTALT PSYCHOLOGY.  
1961 Berkeley, Calif.: University of California Press.

Hohausen, S. ARCHITECTURAL AND INTERIOR MODELS, DE-  
1970 SIGN AND CONSTRUCTION. New York: Van Nostrand.

Since laymen cannot read plans, elevations, perspectives or renderings, this work discusses how to use three-dimensional models to simulate designed environments. Models aid in design, are the most easily understood presentation technique, are accurate, are necessary for hard-to-visualize design forms, are necessitated by new, unusual, highly personal forms and materials, and help sell projects as well. The emphasis here is on the techniques and procedures to use with different tools and materials. Subjects include scales and materials, exterior architectural models, interior models, presentations, and

photography. Examples are extensive and well illustrated, and the work definitely qualifies as a complete guide to model building.

**Ittelson, W.H., Rivlin, L.G. and Proshansky, H.M. THE USE OF BEHAVIORAL MAPS IN ENVIRONMENTAL PSYCHOLOGY. 1970** In H.M. Proshansky, W.H. Ittelson and L.G. Rivlin (Eds.) *Environmental Psychology: Man and His Physical Setting*. New York: Holt Rinehart and Winston.

Behavior always occurs someplace, within the limits of some physical surrounding. Recent recognition of the importance of this self-evident fact has led to a growing number of studies relating various aspects of behavior to the physical spaces in which they are observed. Any data of this kind can be thought of as constituting a *behavioral map*. The necessary features of such a map are descriptions of behavior and of participants and statements relating the behavior to its physical locus. Behavioral mapping as thus defined is a very general technique for studying environmental influences on behavior. As might be expected in any new field of inquiry, this technique has so far not been widely used, but those who have used it have found it extremely fruitful. This work describes procedures for producing and using behavioral maps in the study of environmental psychology.

**Jay, P. ENVIRONMENTAL PERCEPTION: CAN SCIENCE REALLY HELP? *Design*, 220, 52-55.**

We now have a technology that is sophisticated enough to control our environment. This could be of great value—particularly as people increasingly tend to spend most of their working lives in entirely artificial surroundings. But can science really help us to isolate the factors that make the environment pleasant? It appears that, within the rather broad range of environmental conditions to which we can adapt, mental attitude is more important than any other factor, and we should therefore bear three fundamental points in mind. (1) If, merely to earn a living, people have to carry out tasks which seem to them to be without real meaning or interest, in circumstances not of their own choosing, they will com-

plain about anything or everything, and the complaints will not necessarily bear much relation to their physical circumstances. (2) People will complain much less if given some choice in the conditions of their environment. Therefore there should be as much local control of lighting, heating, ventilation and so on as is technically practicable. The efficient functioning of heating and ventilating installations often depends on maintaining a delicate balance, so that local control may be difficult to achieve (which points to one way in which our technology might well be improved). (3) People will accept what they know cannot be helped, and complain about things which they think should have been better. The environment in any new building should therefore be well up to the standard expected by the occupants—a standard which may be very different from that thought necessary or desirable by the office manager, the production engineer or the designer himself. It also follows that higher and higher standards will be demanded for new buildings, without necessarily making those who work in old buildings feel deprived unless they have constant opportunities for comparison. These observations may be disappointing to anyone who started this article in the belief that he was about to be initiated into the secrets of modern science, and he may well complain that everybody knows things like this from his own experience. It is curious that each person knows these things in his capacity as a human being, while in his capacity as an architect, engineer, manager, financier or civil servant he so often forgets them.

Julesz, B. TEXTURE AND VISUAL PERCEPTION. *Scientific American* 1965 212, 38-55.

Jung, C.G. MAN AND HIS SYMBOLS. New York: Doubleday. 1971

Kepes, G. (Ed.) VISION+VALUE SERIES. Braziller Art and Architecture Books. 1966

Kohler, W. THE TASK OF GESTALT PSYCHOLOGY. Princeton, N. 1969 J.: Princeton University Press.

Kolers, P. and Eden, M. RECOGNIZING PATTERNS: STUDIES IN  
1968 LIVING AND AUTOMATIC SYSTEMS. MIT Press.

Langer, S. FEELING AND FORM. New York: Charles Scribner's  
1953 Sons.

Logan, H.L. VISION. Madison, Wis.: University of Wisconsin, Envi-  
1969 ronmental Design Seminar.

Lynch, K. and Rivkin, M. A WALK AROUND THE BLOCK. In H.M.  
1970 Proshansky, W.H. Ittelson, and L.G. Rivlin (Eds.) *Environ-  
mental Psychology: Man and His Physical Setting*. New York:  
Holt Rinehart and Winston.

What does the ordinary individual perceive in his landscape? What makes the strongest impression on him and how does he react to it? To answer these questions, the researchers recorded the impressions of persons as they walked through the city streets. The results showed interesting agreements about what parts of the scene were most remarkable, and how these parts could be fitted together to make a whole. Spatial form seemed to be a fundamental impression. Spatially dominant buildings, of dominant use or association, also appear in the front rank. Of next importance was the quality of the city "floor," or pavement; and the contents and details of the various storefronts.

Luscher, M. THE LUSCHER COLOR TEST. New York: Pocket  
1971 Books.

Maslow, A.H. and Mintz, N.L. EFFECTS OF ESTHETIC SUR-  
1956 ROUNDINGS: INITIAL EFFECTS OF THREE ESTHETIC  
CONDITIONS UPON PERCEIVING 'ENERGY' AND  
'WELLBEING' IN FACES. *J. of Psych.* 41 247-254.

An experiment was conducted as an initial step in studying the effects of esthetic surroundings upon people. Three visual-esthetic conditions were used: "beautiful," "average," and "ugly" rooms. In each room, subjects unaware of the purpose of the experiment were asked to rate the "fatigue/energy" and "displeasure/well-being" of 10 negative-print

photographs of faces. The results were: (a) the group in the "beautiful" room gave significantly higher ratings (more "energy" and "well-being") than groups in either the "average" or "ugly" rooms; (b) the "average" room group had somewhat higher ratings than the "ugly" room group; (c) the mean score for ratings in the "beautiful" room fell in the "energy" and "well-being" range, while the means for the ratings in the other two rooms fell within the "fatigued" and "displeased" range. Discussion pointed out that: (a) suggestion, "role-playing," or variables other than visual-esthetic ones did not account for the differences obtained; (b) there seems at present to be no single visual-esthetic quality that can account for the differences among all three groups; (c) the effects may possibly have been obtained by the affect of the rooms on the subject-examiner relationship.

McLuhan, M. VERBI-VOCO-VISUAL EXPLORATIONS. New York: 1967 Something Else Press.

Mead, G.H. ON SOCIAL PSYCHOLOGY. Chicago: The University of 1964 Chicago Press.

Mead, G.H. PHILOSOPHY OF THE ACT. Chicago: The University 1964 of Chicago Press.

Michelson, W. AN EMPIRICAL ANALYSIS OF URBAN ENVIRON-  
1966 MENTAL PREFERENCES. *J. American Institute of Planners*  
32(4), 355-60.

Although tentative, the data from this research urge the understanding of social diversity and the future utilization of physical diversity in planning cities. They point out two elements of social diversity in the population as prominent for planning physical aspects of the city: value orientations and the nature and extent of social interaction. While their relevance is restricted to segmented dimensions of environment, no one variable being crucial to all of them, these two social characteristics account for great differences in the lives of people, differences which must be taken into consideration by planners, along with more traditional concerns. Furthermore, the conceptual scheme proposed and the data bearing

on it suggest the viability of planning for diversity by concentrating on the basic unit of the individual. Since basic dimensions of environment may be independent of each other, numerous combinations may be constructed from among their variations which will not only accommodate the affected people more expertly, but which on the metropolitan level can present an endless kaleidoscope of forms for cities which ought necessarily to resemble each other no more than their residents do. Diversity is not an end in itself. But when in cities it represents the minimization of social costs and the maximization of benefits to individuals, it represents a goal to cherish no less than others.

Mintz, N.L. EFFECTS OF ESTHETIC SURROUNDINGS: PRO-  
1956 LONGED AND REPEATED EXPERIENCE IN A "BEAUTIFUL" AND AN "UGLY" ROOM. *J. of Psych.*, 41, 459-466.

The present study investigated whether the effects of esthetic surroundings reported previously simply reflect either "laboratory" activity or initial adjustments to the room conditions. During a period of three weeks, two examiners, *unaware* that they were "subjects" for this study, each spent prolonged sessions testing other subjects in a "beautiful" ("B") room and in an "ugly" ("U") room. On a rating scale, the examiners had short-term effects similar to those reported previously; furthermore, during the entire three weeks of prolonged sessions the ratings continued to be significantly higher in the "B" room. The testing-time comparisons showed that an examiner in the "U" room usually finished testing more quickly than an examiner in the "B" room. Observational notes showed that in the "U" room the examiners had such reactions as monotony, fatigue, headache, sleep, discontent, irritability, hostility, and avoidance of the room; while in the "B" room they had feelings of comfort, pleasure, enjoyment, importance, energy, and a desire to continue their activity. It is concluded that visual-esthetic surroundings (as represented by the "B" room and the "U" room) can have significant effects upon persons exposed to them. These effects are not limited either to "laboratory" situations or to initial adjustments, but can be found under naturalistic circumstances of considerable duration.



Nickson, A.F.B. and Muncey, R.W. SOME EXPERIMENTS IN A  
1956 ROOM AND ITS ACOUSTICAL MODEL. *Acustica*, 6,  
295-302.

The feasibility of three dimensional acoustic models employing sound waves appears to be widely accepted, but no experimental evidence is available to corroborate this. Experiments are described in which the acoustic behavior of a space about  $14 \times 5 \times 3 \text{ m}^3$  in the octave about 200 c/s is compared with that of a model at one quarter scale, and it is shown that, for several of the well known objective acoustic tests, the theory that such models are possible is supported. The accuracy attained corresponded with the accuracy with which the surfaces were matched, and was considerably greater than that of the relation of objective testing and subjective impressions.

Norberg-Schultz, C. EXISTENCE, SPACE, AND ARCHITECTURE.  
1971 Praeger Paperbacks, Contemporary Architecture Series.

Proshansky, H.M., Ittelson, W.H. and Rivlin, L.G. (Eds.) ENVIRON-  
1970 MENTAL PSYCHOLOGY: MAN AND HIS PHYSICAL SET-  
TING. New York: Holt Rinehart and Winston.

Rapoport, A. and Kantor, R.E. COMPLEXITY AND AMBIGUITY  
1967 IN ENVIRONMENTAL DESIGN. *AIP Journal* 33(4),  
210-221.

Simplicity and clarity in the intent of much of environmental design is questioned from a number of points of view. Among other work, recent psychological research shows that humans prefer ambiguous, complex patterns in their visual fields and that this seems a fundamental perceptual preference, applying even to infants and laboratory animals. The overall finding in this area of research is that there is an optimal range of perceptual input preferred generally by subjects, with both too simple and chaotically complex visual fields disliked. Building in open-ended, complex, involved, allusive ways is suggested to be more psychologically satisfying than the traditional simplicity and control of the environment sought by many designers. The thinking of a number of designers

and writers on urban problems is examined and shown to support this hypothesis.

Rock, I. and Harris, C.S. VISION AND TOUCH. *Scientific American*, 1967 May 1967, 96-104.

Segall, M.H., Campbell, D.T. and Herskowitz, M.J. THE INFLUENCE OF CULTURE ON VISUAL PERCEPTION. Indianapolis, Ind.: Bobbs Merrill.

Perception is an aspect of human behavior, and as such it is subject to many of the same influences that shape other aspects of behavior. In particular, each individual's experiences combine in a complex fashion to determine his reaction to a given stimulus situation. To the extent that certain classes of experiences are more likely to occur in some cultures than in others, differences in behavior across cultures, including differences in perceptual tendencies, can be great enough even to surpass the ever-present individual differences within cultural groups. This study reports significant differences across cultures in susceptibility to several geometric, or optical, illusions. It should be stressed that these differences are not "racial" differences. They are differences produced by the same kinds of factors that are responsible for individual differences in illusion susceptibility, namely, differences in experience. The findings point to the conclusion that to a substantial extent we learn to perceive; that in spite of the phenomenally absolute character of our perceptions, they are determined by perceptual inference habits; and that various inference habits are differentially likely in different societies. For all mankind, the basic process of perception is the same; only the contents differ and these differ only because they reflect different perceptual inference habits.

Sells, S.B. ECOLOGY AND THE SCIENCE OF PSYCHOLOGY. 1966 *Multivariate Behavioral Research*, 1, 131-44.

In the hierarchy of life sciences, psychology occupies a place between the biological disciplines and the social science disciplines. Traditionally, ecology has been recognized as a branch of biology, while the term "human ecology" has been used to

designate the investigations, principally by sociologists and geographers, of the distributions of human population groups in relation to material resources, health, social, economic, and cultural patterns. These disciplines have produced significant bodies of knowledge and theory and they have developed distinctive journals, literature, and learned societies. No such formal development has yet occurred in psychology, although an ecologic emphasis has become pronounced in recent years and may well be gathering enough momentum to crystallize as a major trend in the next decade. This article reviews developments contributing to the ecologic trend in psychology, discusses the issues and difficulties that must be faced, and draws out the implications of the ecologic emphasis on content and method in psychology.

**Sonnefeld, J. VARIABLE VALUES IN SPACE LANDSCAPE: AN INQUIRY INTO THE NATURE OF ENVIRONMENTAL NECESSITY.** *J. of Soc. Issues* 22(4), 71-82.

This article concludes that neither cultural, social, nor economic bases for classification of environmental preferences are especially effective for assessing spatial and landscape needs. A less conventional distinction based on native/non-native differences has the virtue of broad applicability to the issue of space and landscape. Biased only by environmental experience and personality, this distinction is nicely applicable to contemporary societies characterized by a geographical and social mobility.

**Srivastava, K.K. and Peel, T.S. HUMAN MOVEMENT AS A FUNCTION OF COLOR STIMULATION.** *Milieu* 2(4).

**Stark, L. THE CONTROL SYSTEM FOR VERSIONAL EYE MOVEMENTS.** Berkeley, Calif.: Neurological Control Systems Laboratory, U.C.B. Report NCS 1970-01.

**Stea, D. and Blaut, J.M. NOTES TOWARD A DEVELOPMENTAL THEORY OF SPATIAL LEARNING.** In J. Archea and C. Eastman (Eds.) *EDRA TWO: Proceedings of the Second Annual Environmental Design Research Association Conference.* Pittsburgh, Pa.: Carnegie-Mellon University.

Symington, L.E. REACTION TIME: A BIBLIOGRAPHY WITH AB-  
1971 STRACTS. Human Engineering Laboratories.

Taylor, J.C. LEARNING TO LOOK: A HANDBOOK FOR THE  
1957 VISUAL ARTS.

Victor, J. and Rock, I. VISION AND TOUCH: EXPERIMENTALLY  
1964 CREATED CONFLICT BETWEEN THE TWO SENSES. *Science*, 143 544-96.

Wells, B. INDIVIDUAL DIFFERENCES IN RESPONSE. *ARENA*  
1967 *Architectural Association Journal* 82(908), 167-71.

This article looks at how some individual differences occur in the architectural setting, and describes the procedures used to trace them. It is meant to be an introduction to the method of approach, with a sample of results of significance to user requirement studies. Anyone having much to do with user requirement studies will sooner or later be brought up against the problem of what constitutes a significant minority dissent to a majority response. The mathematical solution would tell one whether the dissenters are statistically significant, yet if only one person dissents, and his reaction is such as to cause him intense unhappiness or even to quit his job or house, that might perhaps be regarded as being more serious than that a significant statistical minority had mild cause for complaint. Optimization may call for any amount of balancing of quantitative and qualitative reactions, but individuals vary tremendously, and the best and most humane solutions will be achieved by those who know most about the causes of individual differences, and are least easily seduced by the tyranny of averages.

Werblin, F. THE CONTROL OF SENSITIVITY IN THE RETINA.  
1973 *Scientific American* 228(1), 70-80.

Wohlwill, J.F. THE PHYSICAL ENVIRONMENT: A PROBLEM  
1966 FOR A PSYCHOLOGY OF STIMULATION IN MAN'S RESPONSE TO THE PHYSICAL ENVIRONMENT. *J. of Social Issues* 22(4), 29-38.

This paper urges the creation of a science of environmental esthetics as a branch of psychology concerned with man's affective response to the qualitative and quantitative features of the world of natural and man-made stimuli surrounding him. Esthetics, to be sure, has not been a particularly flourishing branch of psychology in the past, no more than it has, until recently, represented an area of concern in our social, political and economic life. But the "new look" in the field of motivation is bringing psychologists ever closer to the realm of esthetics. Thus the author finds the time auspicious for experimental psychologists to take their place alongside their colleagues in social psychology, sociology, geography, architecture, planning, etc., in a broadside attack on the problems facing us in improving the quality of our environment.

Wokoun, W. VIGILANCE WITH BACKGROUND MUSIC. U.S. 1963 Army H&L Technical Memo 16-63.

Woods, W.A. and Boudreau, J.C. DESIGN COMPLEXITY AS A DETERMINER OF VISUAL ATTENTION AMONG ARTISTS AND NON-ARTISTS. *J. of Applied Psychol.*, 34, 355-62.

The experiment attempted to arrive at some preliminary conclusions regarding the influence of design complexity in determining visual attraction or attention. It is indicated that art students tend to devote a greater proportion of their observation time to the more complex areas than do non-artists. Variance due to complexity of design is significant for the more sophisticated art groups, as are the differences in mean time spent in viewing the designs. However, significant differences are not found for the less sophisticated groups, indicating that sensitivity to design complexity is a developmental process which increases with age and with level of artistic sophistication. The general pattern of data support the hypotheses that: (1) differences in visual sensitivity and attention do exist between artists and non-artists and between age groups; and (2) art groups are more sensitive to or pay more attention to more complex design units than do non-artists when the factors of color and objectivity have been eliminated from the designs.

**Yarbus, A. EYE MOVEMENTS AND VISION. New York: Plenum  
1967 Press.**

**Zunse, L. VISUAL PERCEPTION OF FORM. New York: Academic  
1970 Press.**

## Chapter IV

### SMALL GROUP INTERACTION

This section includes representative examples of recent literature on social considerations relevant to life on board ship which may have some influence on the crew's reactions to their physical surroundings.

It is in the nature of life aboard a ship to include intermittent periods of containment within the vessel, with reduced opportunity for contact with the outside world. To the extent that this constitutes "confinement," aspects of research dealing with confined environments, such as space ships and submarines, become relevant and are therefore represented here. Conversely, studies based on less confined environments, such as land-based housing, afford opportunity for balanced comparisons, and are therefore also included. A good basic reading list on habitability in the confined environment typical of long-duration space missions can be found in the reference section of *The Intangibles of Habitability During Long Duration Space Missions*, prepared for NASA by T. M. Fraser, M.Sc., M.D., 1968.

Space being at a premium on board ship, certainly more so than on land-based structures, issues of territoriality and privacy become more acute. Work on board ship requires a clear definition of tasks

and hierarchies of jurisdiction, as well as a spirit of cooperation and mutual reinforcement. Studies of group interaction, of institutional organization, and of cultural differences become relevant. Examples of studies dealing with these issues are to be found in this section. Also included are a few studies investigating direct relationships between the physical environment and human behavior or reaction to it. A good representation of recent contributions on the subject of man and his physical setting can be found in *Environmental Psychology: Man and His Physical Setting* (Proshansky, 1970), mentioned in the previous section. A few specific articles from this book are listed in this section.



### SMALL GROUP INTERACTION

Altman, I. AN ECOLOGICAL APPROACH TO THE  
1971 FUNCTIONING OF SOCIAL GROUPS. In J.E. Rasmussen  
(ed.), *Individual and Group Behavior in Isolation and  
Group Behavior in Isolation and Confinement*. Aldine  
Press.

Altman, I., and Lett, E.E. THE ECOLOGY OF INTERPERSONAL  
1970 RELATIONSHIPS: A CLASSIFICATION SYSTEM AND  
CONCEPTUAL MODEL. In J.B. McGrath (ed.), *Social and  
Psychological Factors in Stress*. New York: Holt, Rinehart  
and Winston.

Altman, I. and Haythorne, W. THE ECOLOGY OF ISOLATED  
1967 GROUPS. *Behavioral Science*, 12, 169-182.

This study examines social activity and "territorial" behavior for beds, areas of a room, and chairs in socially isolated and nonisolated dyads. Dyads were formed according to a Greco-Latin square design with composition differences on dogmatism, need achievement, need affiliation, and need dominance. Nine dyads lived in a small room for ten days with no outside contact. Matched controls followed the same schedule, but had access to other people and outside facilities. Men in socially isolated groups showed a gradual increase in territorial behavior and a general pattern of social withdrawal, the latter

reflected in increased time spent alone vs. time spent in joint activities. There also seemed to be a developmental sequence of territorial behavior, with fixed geographical areas and highly personal objects subject to jurisdictional control first, and more mobile, less personal objects somewhat later. There were also interaction effects of social isolation and group composition on social activities and territorial behavior. Incompatibility on traits directly associated with interpersonal matters (dominance and affiliation) resulted in high territoriality, while incompatibility on characteristics relevant to ideas and objects (achievement and dogmatism) did not have strong territorial outcomes. For social activities, personality incompatibility on "egocentric" characteristics (dominance and dogmatism) were associated with high social activity, while incompatibility on "sociocentric" characteristics (affiliation and achievement) led to social withdrawal.

**Baker, R.G.** ECOLOGICAL PSYCHOLOGY. Stanford University  
1968 Press.

**Bates, A.P.** SOME SOCIOMETRIC ASPECTS OF RANKING IN A  
1952 SMALL FACE-TO-FACE GROUP. *Sociometry*, 15,  
330-41.

This study set out to test two hypotheses, one relating social rank in a small group and performance in the group norms, the other relating social rank and volume of interaction. While hypothesis 1 receives some support from the data, the results are a good deal less conclusive than in the case of hypothesis 2, where variation in rank based on certain criteria is closely associated with frequency of interaction. It is somewhat difficult to interpret the findings relative to hypothesis 1, because they were presumably affected to an unknown degree by the methods used and by the fact that the group was new and relatively unstructured.

**Bechtel, R.B.** HUMAN MOVEMENT AND ARCHITECTURE. In  
1970 H.M. Proshansky, W.H. Ittelson, and L.G. Rivlin,  
*Environmental Psychology: Man and His Physical Setting*.

Environmental Psychology Program, City University of New York. San Francisco: Holt Rinehart and Winston, 642-45.

When a person moves around inside a building, he is responding to the building as architecture. If the building is familiar territory, he moves through it in a *habitual* manner; if it is unfamiliar, he moves in an *exploratory* manner. The emphasis on locomotion, both exploratory and habitual, poses special problems for the architect as he works with interior space. How, for example, can he provide a layout that will minimize the visitor's confusion on first entering an unfamiliar public building? Or how can he design a home so as to maximize the family's use of available space as they go about their daily activities? The development of a new measuring device, the odometer, which can indirectly "observe" patterns of movement, has helped provide answers to some of the questions. The odometer is an electrical system for automatically recording the number and location of footsteps across a floor. The device consists of a cluster of electric switch mats covering an entire floor space, with each mat connected to an electric counter. The counters that keep score are housed in a cabinet placed out of sight in a closet or in the next room. A clock is mounted on the face of the counter cabinet to record the amount of time people spend in the room—the clock starts when someone steps on the first mat and stops with the last electrical impulse recorded, when the last person leaves the room.

Becker, F.D. and Mayo, C. DELINEATING PERSONAL DISTANCE  
1971 AND TERRITORIALITY. *Environment and Behavior*,  
3(4), 375-81.

Berkman, P. LIFE ABOARD AN ARMED-GUARD SHIP. *American*  
1971 *Journal of Sociology*, 51, 380.

In port an armed-guard ship, divorced of its primary function, becomes unorganized and tends to lose its shipshape character; a "scattering-ashore" process begins.

The ship, devoid of men and with social interaction reduced to a minimum thereby, disintegrates as a social unit. Under way, with routine duties and collective expectations re-established, the ship assumes a social identity through the development of group solidarity and integration. A landlubber, thrust into this situation, becomes a sailor in a context of shipboard discourse, rough weather and the development of sea legs, informal initiatory ritual, standing watches, general quarters, and the imminence of enemy attack.

Berne, E. THE STRUCTURE AND DYNAMICS OF ORGANIZATIONS AND GROUPS. New York: Grove Press.  
1966

Bion, W.R. EXPERIENCES IN GROUPS. Group Relations Conference II, Wright Institute, Basic Books.  
1959

Experiments in a rehabilitation wing of a military psychiatric neurosis hospital suggest the need for further examination of the structure of groups and the interplay of forces within the groups. Psychology and psychopathology have focused attention on the individual, often to the exclusion of the social field of which he is a part. There is a useful future in the study of the interplay of individual and social psychology, viewed as equally important interacting elements.

Broadbent, D.E. DECISION AND STRESS. London: Academic Press.  
1971

Brolin, B.C. and Zeisel, J. MASS HOUSING: SOCIAL RESEARCH AND DESIGN. *The Architectural Forum*, 129(1), 66-71.  
1968

A prototype study in which observations on social behavior are translated into requirements for appropriate architecture.

Craik, K.H. THE ASSESSMENT OF PLACES. In P. McReynolds  
1971 (Ed.), *Advances in Psychological Assessment*, Vol. II. Palo  
Alto, Ca.: Science and Behavior Books.

This discussion focuses upon the systematic assessment of physical environmental settings, more simply termed *places*. Adaptation of concepts and techniques from the field of personality assessment offers a tremendous methodological resource for the assessment of environments. Five modes of analysis in the comprehensive assessment of places can be distinguished: (1) the physical-spatial properties of places, (2) the organization of entities and components within places, (3) the traits of places, (4) the behavioral attributes of places, and (5) the institutional attributes of places.

Dean, D.G. ALIENATION: ITS MEANING AND MEASUREMENT.  
1961 *Amer. Sociol. Rev.*, 26, 753.

The concept of alienation is considered here as having three minor components: Powerlessness, Normlessness and Social Isolation. Scales constructed to measure these inter-correlated from .41 to .67 (N=384). There is a low but statistically significant *negative* correlation between the three components of alienation and occupational prestige, education, income, and rural background. There is a small *positive* correlation between alienation and advancing age.

Fast, J. BODY LANGUAGE. New York: M. Evans and Co., Inc.  
1970

Festinger, L., Schachter, S., and Back, L. SOCIAL PRESSURES IN  
1950 INFORMAL GROUPS. New York: Harper.

Flising, A., Werelius, B. MANNING OF TECHNICALLY  
1972 ADVANCED SHIPS. The Swedish Ship Research  
Foundation, SSF 7548:2.

**Fraser, T.M. LEISURE AND RECREATION IN LONG DURATION  
1968 SPACE MISSIONS. *Human Factors*, 10(5), 483-88.**

Leisure activities pursued during long-range space missions should not be considered by planners as merely a way of filling time. Current astronaut selection procedure tends to favor those who in leisure time in a spacecraft will spontaneously pursue mission-oriented activities, making the most of whatever facilities are available. With provision of an appropriate climate and opportunity, encouragement can be given to furtherance of the creative use of leisure for self-development of the persons involved. Provision should be made for both active recreation, as in hobbies, communal games, and even music making, and for passive enjoyment as in listening to recorded music and radio, watching television and movies, and reading. Provision for exercise programs is also required.

**Fried, M. and Gleicher, P. SOME SOURCES OF RESIDENTIAL  
1961 SATISFACTION IN AN URBAN "SLUM." *Journal Amer. Instl. of Planners*, 27(4), 305-15.**

Urban renewal planning has assumed that social benefits would accrue to the former residents of slums. But the meanings that the slum areas have for their residents and the consequent effects that relocation would have for them have not been adequately understood. Prior to being removed from Boston's West End redevelopment area, most residents experienced profound satisfaction from living in the area. Their satisfaction derived, in large part, from the close associations maintained among the local people and from their strong sense of identity to the local places. In turn, people and places provided a framework for personal and social integration.

**Geddes, R.L. THE PSYCHOLOGICAL DIMENSIONS OF  
1965 ARCHITECTURAL SPACE. *Progressive Architecture*.**

The idea of designing architecture in terms of social modules is not new. But, when reviewing the majority of recently completed housing projects, college residences,

and institutions for the sick, very little thought has been given to the human element, and design is for the most part a haphazard mechanical procedure. It should be possible to make these buildings workable shelters in the terms discussed in this article. This study points to a logical planning approach, to a method of design.

Gump, P.V. THE BEHAVIOR SETTING: A PROMISING UNIT  
1971 FOR ENVIRONMENTAL DESIGNERS. *Landscape  
Architecture*, 130-34.

The methods by which we divide the environment into units and by which we describe these units have been primitive, vague and inconsistent. The author believes that people's behavior and experience in the environment can be measured and analyzed with new precision by using *the behavior setting* as a standard unit in environmental research. This concept presses designers and other decisionmakers to face the hard fact that to shape the environment into a park, plaza, square or subway produces a milieu for human behavior--and that within this milieu, behavior settings will develop. The designer's work is to be judged by the behavior he induces indirectly through these behavior settings, as well as by the milieu he produces directly.

Gunderson, E. E. K. EPIDEMIOLOGY AND PROGNOSIS OF  
1945 PSYCHIATRIC DISORDERS IN THE NAVAL SERVICE.  
Navy Medical Neuropsychiatric Research Unit, San Diego,  
Calif. Reprint NMNRU-70-15, AD-734-195.

The epidemiology of psychiatric disorders has been investigated in the naval population during the past decade. A continuous file of all Navy and Marine Corps psychiatric patients has been established on computer tapes in order to facilitate epidemiological and longitudinal studies. Psychiatric incidence rates have been found to vary widely among different segments of the naval population. Incidence rates increased sharply for Marine Corps enlisted personnel during the Vietnam war,

compared with an earlier peace-time period. Short-term prognostic studies have been conducted for both psychiatric outpatients and inpatients. Long-term prognosis has been investigated in severe psychiatric disorders, and different prognostic indicators were found for neurotics and psychotics.

Hall, E.T. PROXEMICS AND DESIGN. *Design and Environment*.  
1971

Hall, E.T. HUMAN ADAPTABILITY TO HIGH DENSITY. *Journal of Ekistics*, 20(119).  
1969

Hall, E.T. THE HIDDEN DIMENSION. Garden City: Doubleday &  
1966 Company, Inc.

Hall, E.T. THE SILENT LANGUAGE. New York: Fawcett World  
1959 Library.

Hare, A.P. and Bales, R.F. SEATING POSITION AND SMALL  
1963 GROUP INTERACTION. *Sociometry*, 26, 480-86.

The analysis of several sets of data from five-man laboratory groups tends to support the hypothesis that both centrality of seating position and distance between members can be used to predict the interaction pattern. This pattern only appears in a "task" session. In a "social" session for the same type of group, members tend to talk more to the person next to them as they turn away from the group for a more intimate conversation. Personality variables are also related to seating choice and to interaction rate. More dominant subjects tend to choose the central seats and to do the talking.

Herbst, P.G. SOCIO-TECHNICAL AND PSYCHODYNAMIC  
1968a VARIABLES IN SHIP ORGANIZATION DESIGN. Work  
Research Institutes, Oslo, Norway.



Herbst, P.G. SOCIO-TECHNICAL DESIGN OF SHIP  
1968 ORGANIZATION. Work Research Institutes, Oslo,  
Norway.

Ittelson, W.H., Proshansky, H.M., and Rivlin, L.G. THE ENVIRON-  
1970 MENTAL PSYCHOLOGY OF THE PSYCHIATRIC  
WARD. In Proshansky, Ittelson, and Rivlin (Eds.), *En-  
vironmental Psychology: Man and his Physical Setting*.  
New York: Holt, Rinehart, and Winston, 419-39.

Izumi, K. PSYCHO-SOCIAL CONSIDERATIONS OF  
1968 ENVIRONMENTAL DESIGN. National Society of  
Interior Designers, New York.

Joiner, D. SOME SOCIO-CULTURAL INFLUENCES ON THE USE  
1970 OF ARCHITECTURAL SPACE. *Architectural Psychology  
Newsletter*, Sec. 2.

Kipnes, D.McB. INTERACTION BETWEEN MEMBERS OF CREWS  
1957 AS A DETERMINANT OF SOCIOMETRIC CHOICE.  
*Human Relations*, 10(3).

The study tested the general hypothesis that sociometric preferences of members of bomber crews are a function of the formal organization of the crew. The crew organization is such that a specific physical position in the plane and specialized job responsibilities are assigned to each man. Both physical positions and job responsibilities enhance or restrict the opportunities for interaction among crew members. The article hypothesizes that crew members would be best liked by others who had greatest opportunity for interaction with them. The results support the conclusion that interpersonal preferences of crew members are affected by the crew organization, and that greater amounts of contact (resulting from organizational requirements) facilitate the development of stronger preferences.

Kueth, J.L. PERVASIVE INFLUENCE OF SOCIAL SCHEMATA.  
1966 *J. Abnorm. and Soc. Psych.*, 68(3), 248-54.

Subjects placed human figures cut from felt on a field under free response instructions and then reconstructed displays of the figures in a judgment task where the figures were presented with a fixed separation and replaced by the subjects. Next the subjects attempted to replace human statuettes while blindfolded. Finally, a word association test was administered. Those subjects who kept man and woman figures together in free placements made the largest errors of replacing man-woman pairs in figures closer together than they replaced other pairs in both the visual and nonvisual reconstructions. These subjects were significantly more likely to give "man" and "woman" as reciprocal verbal associations. The same social schema was aroused by the specific content whether the stimuli were visual, nonvisual, or verbal.

Kueth, J.L. SOCIAL SCHEMAS. *J. Abnorm. and Soc. Psych.*,  
1962 64(1), 31-8.

Subjects placed sets of figures cut from felt on a felt board under conditions of free response. Most subjects responded to the task by giving organized responses; scattered or apparently random placement of figures was rare. The content of a set of figures determined the schema that was employed by the subject in organizing his response. A strong basic social schema results in the grouping of human figures to a greater extent than non-human figures. Several specific social schemas showed high commonality such as the tendency to place a child nearer to a woman than to a man and the tendency to place a dog nearer to a man than to a woman. The clinical significance of idiosyncratic responses was discussed. A separate study showed that social schemas are social response sets in the sense that they can produce constant errors when subjects attempt to reconstruct situations that they have previously observed.

Kuhn, M. RESEARCHES IN HUMAN SPACE. *Ekistics*, 25.  
1968

Lee, T. THE EFFECT OF THE BUILT ENVIRONMENT ON  
1971 HUMAN BEHAVIOR. *Intern. Journal Environmental  
Studies*, 1, 307-14.

A primary issue to be faced by the student of human urban behaviour is that of determinism. There is disagreement among social scientists on whether or not the human personality is partly shaped by the built environment. The main arguments are presented and the implications for planning are also discussed.

Leibman, M. THE EFFECTS OF SEX AND RACE NORMS ON  
1970 PERSONAL SPACE. *Environment and Behavior*, 2(2),  
208-46.

Data on the nature of the relationship between social norms and spatial behavior have important implications for the study of environmental and social psychology. Results indicate that the social environment is a significant determinant of the perception and use of space, and that spatial behavior is an important measure of the behavioral consequences of social factors. While notions of context and salience are not new, these findings underscore their significance in the investigation of social and environmental forces.

Lewis, R. OFFICER-ENLISTED MEN'S RELATIONSHIPS. *Am.*  
1946 *Journal of Sociology*, 52, 410.

The first reaction of the enlisted man to his officers is one of envy. He is jealous of his superior's elevated position and yearns for similar status. As his training and contact with officers increase, he becomes resentful of his officer's superior attitude and special privilege. In officer candidate schools the potential officer is indoctrinated to an attitude of superiority to his troops. This attitude is fortified, upon commission, by the awareness of special privilege which is now his. Re-examination and reorganization of officer-enlisted men's relationship is necessary for the development of a more efficient army.

Lipman, A. BUILDING DESIGN AND SOCIAL INTERACTION.  
1968 *Architects Journal, London*, 23-30.

Little, K.B. CULTURAL VARIATION IN SOCIAL SCHEMATA. *J.*  
1968 *of Personality and Soc. Psych.*, 10(1), 1-7.

Social interaction distances among five national groups, United States American, Swedish, Greek, Southern Italian, and Scot, were studied using doll placements to elicit 19 different social schemata. There was considerable agreement among the groups as to the ordering of the distances for the different transactions, but significant differences among nationalities as to the mean distance at which the various interactions were judged as taking place. The hypothesis that the Mediterranean culture subjects would have closer interaction distances as compared to North European subjects was confirmed at a high level of significance; the hypothesis that *all* interaction involving female surrogates would be seen as occurring at closer distances than those involving males was not supported. In general, female-female transactions of an intimate nature, or those involving unpleasant topics, will be judged as occurring at closer distances than male-male interaction. For interactions with authority figures or with superiors, on the other hand, the female-female distances will be judged as occurring at substantially greater than male-male. (Since the subjects in this study were always the same sex as the stimulus figures this conclusion cannot be generalized to cross-sex judgments.) The major single factor determining distances in dyadic schemata appears to be the relationship between the members with the specific content or affective tone of the transaction as the next most important.

Lyman, S.M. and Scott, M.B. TERRITORIALITY: A NEGLECTED  
1967 SOCIOLOGICAL DIMENSION. *Social Problems*, 15,  
236-49.

Territoriality, or the attempt to control space, is conceived as a fundamental human activity. Distinguished are four

types of territory: public territories, home territories, interactional territories, and body territories. There also exist three types of territorial encroachment, (violation, invasion, and contamination) and three types of reaction to encroachment, (turf defense, insulation, and linguistic collusion). Certain groups are spatially deprived of free territory—that is, the ecological conditions that afford opportunities for idiosyncrasy and expression of desired identities. In response to this absence of free space, spatially deprived groups respond to various kinds of body manipulation, body adornment, and body penetration, (the modification of inner space).

**Maas, H. THE HUMAN FACTOR IN LIFE ON BOARD SHIP.**  
1959 *Weltschiffahrts-Archiv* 4, Bremen.

This paper presents the results of a conference of qualified personalities in shipping at the "Evangelische Akademie" in Loccum on the theme "The human factor in life on board ship".

**Mann, P.H. THE STATUS OF THE MARINE RADIO-MAN. A  
1957 BRITISH CONTRIBUTION.** *Am. Journal of Sociology*,  
63(1), 39.

The marine radioman in the British Merchant Navy has officer status, but, because of the special nature of his role, his status does not fit easily into the general officer hierarchy of the average merchant ship. It is suggested that in both the formal and the informal social structure of the ship's company there are many factors which result in the radio officer's being odd man out.

**Mehrabian, A. and Diamond, S.G. SEATING ARRANGEMENT  
1971 AND CONVERSATION.** *Sociometry*, 34(2), 281-89.

This study examined seating preferences as a function of sex, affiliative tendency and sensitivity to rejection, and the effects of seating choice on conversation. The findings indicated that in four-person groups females and more affiliative subjects had a greater preference for closer

positions. However, there were no significant relations between sex or the personality measures and preferences of orientation. There was more conversation between persons in more immediate positions, i.e., those seated closer and/or more directly oriented to one another. But, the finding relating distance to conversation applied only to those who were sensitive to rejection. The present findings supplement earlier results and suggest a two-sided relation between immediacy and liking: people who like each other select more immediate positions relative to one another, and immediate positioning of strangers leads them to communicate liking to each other.

Otterland, A. A SOCIOMEDICAL STUDY OF THE MORTALITY  
1960 IN MERCHANT SEAFARERS. In Aubert and Arner, *The Ship As A Social System*. Gothenberg.

Radloff, R. and Helmreich, R. GROUPS UNDER  
1968 STRESS-PSYCHOLOGICAL RESEARCH IN SEALAB II. New York: Appleton-Century-Crofts.

Record, J.C. THE MARINE RADIOMAN'S STRUGGLE FOR  
1957 STATUS. *Am. Journal of Sociology*, 62(4).

Labor solidarity can be breached not only by jurisdictional disputes, ideological differences, and personal rivalries but by struggle for status. The merchant-marine radio operator, marginal man of a hierarchical shipboard society, used his union as an instrument of upward mobility to dissociate himself from common crew members and rise into the officer ranks. Not satisfied to write officer privileges into its collective-bargaining contracts, the union successfully sought congressional confirmation of the higher status, only to have its members continue to encounter something less than full acceptance by deck and engineering officers, who are organized in separate craft unions.

Richardson, S.A. ORGANIZATIONAL CONTRASTS ON BRITISH  
1956 AND AMERICAN SHIPS. *Administrative Science Quarterly*, 1(2).

To determine some of the common denominators and

variations that occur cross-culturally in social organizations, a comparison is made between the crews of British and United States merchant ships. This type of organization was selected because such ships have an identical purpose and similar environments irrespective of nationality. Differences are described and analyzed in the training, social control, and stratification of the deck departments.

Rioch, M.J. "ALL WE LIKE SHEEP—" (ISAIAH 53:6):  
1971 FOLLOWERS AND LEADERS. *Psychiatry*, 34, 258-73.

The full verse in the King James version of the Bible from which the title of this paper is taken is: "All we like sheep have gone astray; we have turned everyone to his own way; and the Lord hath laid on him the iniquity of us all." The passage might be interpreted and enlarged upon in more contemporary idiom something like this: "All of us are baffled in these troubled times and we don't know which way to turn. Each one is doing his own thing; but that is not really as satisfying as being committed to a common goal or belonging to a stable community. Surely somewhere there is a good leader who knows the answer, but our actual leaders are bad and are responsible for all our ills and ailments."

Rioch, M.J. THE WORK OF WILFRED BION ON GROUPS.  
1970 *Psychiatry*, 56-66

Since 1965 the Washington School of Psychiatry has sponsored a series of residential Group Relations Conferences in the tradition developed in England by the Centre for Applied Social Research of the Tavistock Institute of Human Relations. The focus of these conferences is the group as a whole dynamic field in relationship to other fields. Their uniqueness lies in the highly disciplined concentration on the part of the staff upon this focus. The individual's personal life has individual characteristics, and his dyadic relationships are not the subject of study. A grasp of the work in this area by the British psychoanalyst Wilfred Bion can be helpful not only to participants in these conferences but to anyone who is occupied with groups.

Schwartz, B. THE SOCIAL PSYCHOLOGY OF PRIVACY. *Amer. J. of Sociology*, 73(6), 741-52.  
1968

Patterns of interaction in any social system are accompanied by counter-patterns of withdrawal, one highly institutionalized (but unexplored) mode of which is privacy. There exists a threshold beyond which social contact becomes irritating for all parties; therefore, some provision for removing oneself from interaction and observation must be built into every establishment. Such provisions subserve the action patterns for which they provide intermission. Privacy, which is bought and sold in social establishment, reflects and affirms status divisions, and permits "localized" deviation which is invisible to the group as a whole. Privacy thereby insulates against dysfunctional knowledge. Rules governing entrance into and exit from privacy are most clearly articulated on the level of the establishment and are reflected in its physical structure and in proprieties concerning the uses of space, doors, windows, drawers, etc. The report ends with a discussion of identity and its relation to the freedoms of engagement and disengagement.

Scrole, L. SOCIAL INTEGRATION AND CERTAIN  
1956 COROLLARIES: AN EXPLORATORY STUDY. *Amer. Sociol. Rev.*, 21, 709.

Sommer, R. PERSONAL SPACE—THE BEHAVIORAL BASIS FOR  
1969 DESIGN. Englewood Cliffs: Prentice-Hall, Inc.

Sommer, R. SMALL GROUP ECOLOGY. *Psychological Bulletin*,  
1967 67(2), 145-62.

The systematic study of the arrangement of individuals in small groups began in 1950 using post hoc analysis of data collected for other purposes. Only recently have investigators begun to design experiments with group ecology as the major independent variable. Results have shown that spatial arrangement is a function of group task, the degree of relationship of individuals, personalities of



the individuals, and the amount and kind of available space. The resulting arrangement in turn affects communication, friendship, and status differentiation between individuals. Knowledge of small group ecology can help in developing a theory of social relationships that includes the environment in which interaction takes place as well as principles for designing functional environments from the standpoint of human relationships.

Sommer, R. and Becker, F.D. ROOM DENSITY AND USER  
1971 SATISFACTION. *Environment and Behavior*, 3(4),  
412-17.

Stilitz, I.B. BEHAVIOUR IN CIRCULATION AREAS.  
1969 Environmental Research Unit, University College, London.

Theodorson, G.A., (Ed.). STUDIES IN HUMAN ECOLOGY.  
1961 Evanston, Ill.: Row, Patterson.

Wells, B. THE PSYCHO-SOCIAL INFLUENCE OF BUILDING  
1965 ENVIRONMENT. *Building Science*, 1, England, 153-65.

Winkel, G.H. and Sasanoff, R. AN APPROACH TO AN OBJECTIVE  
1970 ANALYSIS OF BEHAVIOR IN ARCHITECTURAL  
SPACE. In H.M. Proshansky, W.H. Ittelson and L.G.  
Rivlin, *Environmental Psychology: Man and His Physical  
Setting*, Environmental Psychology Program, City  
University of New York. San Francisco: Holt Rinehart and  
Winston, 619-31.

This report concerns one step in a continuing series of related studies seeking to provide a laboratory tool for the *experimental* study of behavior in architectural environments. The initial purpose of this project was to assess the feasibility of bringing a real world environment into the laboratory via what is termed "simulation." Photographic representation was used to simulate a real world system. Color photographs of the interior of a museum were used to allow observers to report on how they would move through the museum and which exhibits

they would view. Observed patterns of user movement in the real world system were compared with the patterns of user movement obtained in the simulated space.

Witzleben, H.D. von. ON LONELINESS. *Psychiatry*, 21, 37-43.  
1958

## Chapter V

### SUBJECTIVE RESPONSES TO COLOR

This chapter includes entries and abstracts of studies pertaining to the affective and perceptual aspects of subjective response to color. It has been assembled primarily as a reference aid to designers concerned with the selection and application of color in environments where the subjective response of the occupant or viewer is important.

An interesting and extensive description of studies dealing with the affective response to color is provided in *The Aesthetics of Color: A Review of Fifty Years of Experimentation* by Ball (1965). *Color Harmony: An Annotated Bibliography*, prepared by Judd for the National Bureau of Standards in 1950, contains summaries of 44 items on the subject of color harmony. A recent study, "The Role of Spectral Energy of Source and Background Color in the Pleasantness of Object Colors," by Helson and Lansford (1970), provides perhaps the most reliable information on color harmony presently available.

Any survey of the literature on the perceptual aspects of color with respect to design of spaces should include "The Long and Short of Color Distance" by Hanes (1960). An architect, Hanes comments on the ambiguity of previous studies of perceptual response to color as well as the inadequacy of designers' rules-of-thumb for color applica-

tions, and describes an original experiment which produced results that refuted many of them.

Two texts which contain sections with exceptionally good overviews of the experimentation pertaining to the subjective response to color are: *Color: A Guide to Basic Facts and Concepts* by Burnham, Hanes and Barileson (1963); and *The Science of Color*, by the Committee on Colorimetry of the Optical Society of America.

### SUBJECTIVE RESPONSES TO COLOR

Allen, E.C. and Guilford, J.P. FACTORS AFFECTING THE  
1936 AFFECTIVE VALUES OF COLOR COMBINATIONS. *The American Journal of Psychology*, 48(4), 643-8.

The imperfectness of Guilford's proposed quantitative law of affective combination by which the affective value of a combination of two colors can be predicted from the affective values of its two components, was the reason for this study. Forty-five color combinations were selected as to difference in hue, tint and chroma. Ten observers, 5 men and 5 women, judged the affective values of the combinations using a rating scale method. The following conclusions were indicated by the results: (1) The law of affective combination was fully verified; the affective value of a combination is highly dependent upon the affective values of the components. (2) There is some evidence that either very small or very large differences in hue give more pleasing results than do medium differences. (3) The affective value of a combination is positively correlated with the amount of contrast in tint, regardless of whether the difference in hue is great, medium or small. (4) There is a slight preference for combinations with small differences in chroma rather than large differences. This is a negligible factor in the case of men.

Allison, R.C., Carswell, W.E., and Dean, G.F. COLOR AND THE  
1961 USE OF COLOR BY THE ILLUMINATING ENGINEER.  
Illuminating Engineering Society, New York, 1961.

This report was developed by the Color Committee of the Illuminating Engineering Society to fill the need for color guidance for the practicing illuminating engineer. Included are discussions of color dimensions, color schemes, and color psychology in respect to interior applications. A step-by-step system for determining suitable interior colors is presented. The report concludes that logical decisions can help decide the dominant hue, value, chroma and contrast best suited to the prevailing conditions, but from there on, the disposition of these colors, their harmonious relationships, and their adaptation to existing and unchangeable conditions in the room, depend on the inherent sense of color and the good judgment of the person who puts them to use.

Bacon, M.M., Rood, E.A. and Washburn, M.F. A STUDY OF  
1914 AFFECTIVE CONTRAST. *American Journal of Psychology*,  
25, 290-3.

How a pleasant experience can be heightened through contrast with a disagreeable preceding experience and vice versa was investigated in this experiment. Affective judgments were made by 37 observers about 18 colors presented after a previously selected pleasant color, and again after a previously selected disagreeable color. The observers worked without knowledge of the purpose of the experiment. The results demonstrated the heightening influence of affective contrast. In a similar experiment, the observers were informed of the purpose of the test. No effect of contrast was demonstrated in these results.

Ball, Victoria K. THE AESTHETICS OF COLOR: A REVIEW OF  
1965 FIFTY YEARS OF EXPERIMENTATION. *The Journal of Aesthetics and Art Criticism*, 23(4), 441-52.

Aspects of the scientific literature which relate to the subject of how color affects people aesthetically are considered. The

conception of aesthetics in this study is limited to an attempt to understand the value estimates which affective responses may induce to the pleasant-unpleasant, beautiful-ugly continuum. Over 50 references to specific studies of experimental work in color aesthetics are made and discussed. The progression from concern for people's color preferences is traced through to our present attempts to predict those preferences in a quantitative way.

**Birren, F. COLOR AND MAN-MADE ENVIRONMENTS.** *American Institute of Architects Journal*, (8), 15-19, (9), 35-39, (10), 37-40.

Biological, psychological and psychic effects of illumination in the man-made environment are discussed. Most artificial environments today expose people to unbalanced light sources. The current need is one of ultraviolet light which leaves the question of how much is required for a beneficial biological result. Color effects tend to be toward the red and the blue; the yellow and green area of the spectrum being neutral. Color in architecture today is too bland, and this can lead to psychological and emotional monotony. Variety and contrast within reason and within the requirements of recognized scientific practice is needed.

**Birren, F. COLOR FOR INTERIORS.** Whitney Library of Design. 1963

The work is composed of two parts, the first of which is an historical review, and the second of which is a discussion of modern principles. In the second part, the author expands on the new functionalism that is coming to influence the use and application of color. This is done in separate sections which deal with various types of applications: hospitals, schools, industrial plants, offices, stores, theaters, hotels, restaurants, and homes. Color charts illustrate appropriate colors selected by the author for these applications. References to specific color studies are not included.

Bullough, E. ON THE APPARENT HEAVINESS OF COLORS. *The*  
1907 *British Journal of Psychology*, 2(2), 111-52.

In order to determine apparent weight of colors, presentations of two identically shaped geometrical figures, each composed of two colors placed one above the other so that the upper and lower colors were reversed in each case, were rated by 50 subjects as to which arrangement they preferred together with the reason for each choice. Darker colors were found to appear heavier than lighter colors.

Burnham, R.W., Hanes, R.M., and Bartleson, J.C. COLOR: A GUIDE  
1963 TO BASIC FACTS AND CONCEPTS. (Chapter 12: Experimental Color Aesthetics). New York: John Wiley & Sons, 206-19.

Various subjects concerning the aesthetic significance of color and the capacity of color stimuli to evoke affective responses are discussed. Methods typically used in experimental studies of color aesthetics (pair comparisons, order of merit, successive categories, and absolute judgment) are explained. The subjects fall generally into two groups, *i.e.*, preference for single colors and color harmony. Several aspects of color that are not primarily affective but that do possess aesthetic interest and are similar in the sense that they are all derived reactions to color are briefly reviewed. These derived reactions to color are: apparent warmth, coolness, weight, and size.

Burnham, R.W. COMPARATIVE EFFECTS OF AREA AND  
1952 LUMINANCE ON COLOR. *American Journal of Psychology*, 65(1), 27-38.

The specific problem of this study was to determine the relative color changes in surface colors for variations in their visual angle and in their luminance. Eight observers manipulated a colorimeter to match eight test-colors of two



sizes and under two photopic levels of illumination. Within the ranges studied, a given area of color appeared slightly brighter and perceptibly more saturated at higher levels of luminance than at lower levels, and colors at a given level of luminance appeared brighter and more saturated in larger areas.

Burnham, R.W. THE DEPENDENCE OF COLOR UPON AREA.  
1951 *American Journal of Psychology*, 64(4), 521-33.

This investigation represents an attempt to measure differences in the appearance of certain colored surfaces as they occupy greater and greater portions of a visual field of uniform brightness. Four observers mixed colorimetric primaries to match test-colors varying in visual angle from 2 degrees to 77 degrees, and the differences in the matching mixtures were found to be significant. As the visual angle was increased from 2 degrees to 22 degrees, the matching mixtures increased generally in excitation-purity; from 22 degrees to 77 degrees there was a tendency for excitation-purity to remain the same or decrease. There was a greater change in chromaticity between visual angles of 2 degrees and 22 degrees than between 22 degrees and 77 degrees.

Committee on Colorimetry, Optical Society of America. THE  
1953 SCIENCE OF COLOR. (*Psychological Concepts: Perceptual and Affective Aspects of Color*). New York: Thomas Y. Crowell Co., 145-71.

Different modes in which color perceptions occur are discussed as the context in which color is perceived. Color perception is described in the illuminant mode, illumination mode, surface mode, volume mode, and film mode. Color constancy is explained. A well-referenced discussion of the affective aspects of color includes sections on color preferences, color harmony, appropriateness of colors, strong

emotional responses, and related impressions. The unitary nature of color perception is acknowledged. The author primarily responsible for this material is Dr. S.M. Newhall.

De Camp, J.E. THE INFLUENCE OF COLOR ON APPARENT  
1917 WEIGHT. A PRELIMINARY STUDY. *Journal of Experimental Psychology*, 2, 347-70.

This study attempts to answer the question: Is color in any way a determinant of the apparent weight of an object? Sixty-three subjects lifted blocks of different colors and compared their apparent weights. They also selected the two most pleasing and least pleasing blocks. The following conclusions were suggested: (1) The influence of the color of an object upon its apparent weight is relatively slight. (2) There is a tendency in many cases to judge a red or black object to be slightly heavier than a yellow or blue object of the same weight. (3) The influence of these colors is not due to their tint value alone; it seems necessary to consider their hue as a minor factor. (4) There is no simple correlation between the affective quality of a color and its influence upon apparent weight.

Ditchburn, R.W. EYE MOVEMENTS IN RELATION TO  
1961 PERCEPTION OF COLOR. In *Visual Problems of Color*, Vol. 2. New York: Chemical Publishing Company, Inc., 51.

It has been possible to arrange that the eye movements control the movements of a target so that its image remains on the same part of the retina even when the eye moves. The image so produced is called the stabilized retinal image. It was found that there is an effective desaturation of all hues when the subject views a stabilized image. Under certain conditions of imperfect stabilization, all colors are seen as white even when perception of form is still fairly good. It is, however, much easier to produce desaturation of blue and green than of red, and there is other evidence that the discrimination of red is based on a process very different from that which is operative for blue and green. An attempt to detect small local clusters of receptors with special

properties has given a negative result. The way in which eye movements may affect perception of hue is discussed. The possibilities and the difficulties of further investigations are surveyed.

Eysenck, H.J. A CRITICAL AND EXPERIMENTAL STUDY OF  
1941 COLOR PREFERENCES. *American Journal of Psychology*,  
54(3), 385-94.

Three questions were investigated, all connected with preferences for simple colors: general preference, saturation factor, and sex difference. Experiments were conducted with a total of 42 subjects of both sexes who ranked 10 Ostwald colored papers, 5½ by 3½ inches, mounted on a single board. Included were six fully saturated colors, three tints, and one shade. The results were: (1) There is a certain amount of agreement between color preferences of people. (2) Subsidiary to this general factor of preference for colors is a bipolar factor, which divides those who prefer saturated colors from those who prefer unsaturated colors. (3) There is a high agreement between the two sexes with regard to their color preferences, apart from a slight preference for orange among the men and yellow among the women.

Faulkner, W. ARCHITECTURE AND COLOR. (Chapter 12: Color  
1972 Harmony). New York: Wiley-Interscience, 119-34.

Judd's principles of color harmony are reviewed. The author maintains that of all the principles associated with color harmony (such as order, dominance, and unity), the greatest of these is unity. The *Color Harmony Manual*, based on the Ostwald system, is explained and compared with the *Munsell Book of Color*.

Gerard, R.M. COLOR AND EMOTIONAL AROUSAL. *American*  
1953 *Psychologist*, 13, 340.

This study investigated the effect of different colors on psychophysiological measures indicative of emotional changes. Blue, red, and white lights of equal brightness were each

projected for 10 minutes on 24 normal adult males. The autonomic nervous system and visual cortex were significantly less aroused during blue than during red or white illumination. Different colors also elicited significantly different feelings, for instance: greater relaxation, less anxiety and hostility during blue; more tension and excitement during red illumination. Manifest anxiety level was significantly correlated with increased physiological activation and subject disturbance during red stimulation. Findings in the opposite direction of quiescence and relief suggested that blue illumination may benefit individuals with chronic tension and anxiety. Implications of the results for Rorschach theory, psychodiagnosis, and color therapy are discussed.

Goldstein, K. SOME EXPERIMENTAL OBSERVATIONS  
1942 CONCERNING THE INFLUENCE OF COLORS ON THE  
FUNCTION OF THE ORGANISM. *Occupational Therapy  
and Rehabilitation*, 21(3), 147-51.

Conclusions about the influence of color on the behavior of the organism were drawn from some experimental examples. Deviations in motor reactions were shown to be greater when subjects were exposed to yellow and red stimulation than when exposed to green and blue stimulation. These visible phenomena were shown to correspond to definite feelings, showing that the individual under the influence of various colors differs in his entire attitude toward the world. Red was found to increase the abnormality of pathological behavior while green brought pathological behavior nearer to normality. Finally, red is inciting to activity and favorable for emotionally-determined actions; green creates the condition of meditation and exact fulfillment of the task. Red may be suited to produce the emotional background out of which ideas and action will emerge; in green these ideas will be developed and the actions executed.

**Granger, G.W. AREA BALANCE IN COLOR HARMONY: AN  
1953 EXPERIMENTAL STUDY. *Science*, 117, 59-61.**

This investigation attempts to answer two questions: First, is there some measure of general agreement between individual preferences for area-balance of color, and second, if such agreement exists, to what extent can it be accounted for by Moon and Spencer's formula on one hand and Munsell's on the other? Twenty subjects adjusted the areas of 32 pairs of Munsell color patches to give the most pleasing balance. It was found that the amount of agreement between individuals' preferences was remarkably high. The results indicate that Munsell's formula can account to a considerable extent for subject's preferences. On the other hand, Moon and Spencer's formula has no predictive value.

**Gundlach, C. and Macoubrey, C. THE EFFECT OF COLOR ON  
1931 APPARENT SIZE. *American Journal of Psychology*, 43(1), 109-11.**

This investigation was an attempt to check the results of a previous experiment by Warden and Flynn which concluded that the color-size illusion did not depend upon the quality of the color or the contrast effect of the immediate context. This was done by first duplicating their method (order of merit), then using a different method (paired comparison). In the second case, 35 subjects, 12 men and 23 women, judged the size of boxes covered with 8 different colors of paper by paired comparisons. The repetition of Ward and Flynn's study failed to confirm their findings. The results of the paired comparison method revealed a marked and consistent effect of color on apparent size, and this effect appears to be directly related to luminosity of the colors involved. Light objects appear comparatively large, and dark objects comparatively small.

**Guilford, J.P. THE PREDICTION OF AFFECTIVE VALUES.  
1931 *American Journal of Psychology*, 43(3), 469-78.**

This study was an attempt to predict the affective values of color combinations when the affective values of the

individual components were known. The subjects, including 249 men and 211 women, made comparison judgments as to the pleasantness and unpleasantness of five single colors and ten combinations of the five colors. The color stimuli were circular patches of light five inches in diameter, projected from behind a ground glass screen. Various mathematical functions, linear and non-linear, were assumed and measurements adjusted to them. Highly valid predictions were possible for the men, but not for the women. There were some indications that the summation of feeling is an additive one and not a product, and that the combined value is not an algebraic sum but a weighted mean, or some simple functions of the most and least pleasant components in the combination. It was suggested that there is a limit to the prediction of an "affective whole" from its "components".

Guilford, J.P. THE AFFECTIVE VALUE OF COLOR AS A  
1934 FUNCTION OF HUE, TINT, AND CHROMA. *Journal of Experimental Psychology*, 17(3), 342-70.

The purpose of this study was to determine if there might be some fundamental functional relationship between affective value and the three variables of color, hue, tint, and chroma. Forty colors, evaluated for hue, tint, and chroma on the Munsell Scheme, were judged repeatedly for affective value by five men and five women subjects. The following conclusions were reached: (1) Hue determined affective value to the extent of about 67 percent for the women and 16 percent for the men. (2) Tint determined affective value about 20 percent for the women, but only 5 percent for the men. In both cases, the lighter the tint the more pleasing the color. (3) Chroma determined affective value only about 5 percent for the women but 13 percent for the men, the saturated colors being preferred to the less saturated. (4) The three attributes combined account for at least 71 percent of the affective value of color for women and 26 percent for the men. (5) There are other common factors that determine the affective value of colors. These can be identified after the effects of hue, tint, and chroma have been eliminated. (6) There are two distinct systems of

color preference: one is a yellow-blue affective discrimination, the short light waves being more agreeable than the long; the other system is a red-blue-green preference over yellow, blue-green and red-violet.

Guilford, J.P. and Smith, P.C. A SYSTEM OF  
1959 COLOR-PREFERENCES. *American Journal of Psychology*,  
72(4), 487-502.

In a systematic study, the affective values of 316 different color specimens in the form of 2-inch squares of paper, were rated by 20 men and 20 women on two different occasions. Smoothed graphic adjustments of the data were made to curvilinear functional relationships, from which isohedonic charts were constructed showing the loci of equal preference values applying to all colors in the color solid. Preferences were highest in the region of green to blue and lowest in the region of yellow and yellow-green, when brightness and saturation were held constant. With few exceptions, affective value was found to be positively related to brightness and saturation, all relationships being curvilinear. Predictions of affective values from the specified hue, brightness, and saturation of colors were generally excellent within the sample. Predictions of a more general scope will depend upon information concerning other populations, other variables of color stimuli, other viewing conditions, and particular uses of colors.

Habitability Technology Section, Space Design Division, Manned  
1971 Spacecraft Center. COLOR. In *Habitability Data Handbook*,  
Vol. 2, Architecture and Environment, NAS-063,  
MSC-03909, 3-71-3-80.

Color will be used to provide visual stimulation for the occupants of extra-terrestrial habitats and to create different moods for relieving the monotony of prolonged confinement. Factors required in color planning, room volume, function, and desired behavioral aspects are covered. Definitions of color attributes and color combinations are included. Emotional responses to color are determined as either desirable or undesirable for particular habitable areas.

Single hues and combinations of hues are grouped according to the emotional response they are capable of inducing.

Hale, W.N., Linn, A., and Quinn, F.R. CONSUMER COLOR  
1964 CHARTS. Baltimore: Munsell Color Company.

This color chart set and its text were specifically designed as a color relationship reference for consumers to use when making color choices in clothing and home furnishings. A color family chart and a personal coloring-home furnishings chart aid one in making harmonious color selections while the text includes some explanation of color application theory.

Hanes, R.M. THE LONG AND SHORT OF COLOR DISTANCE.  
1960 *Architectural Record*, 254-6.

The effect of color on apparent room size was studied to check the validity of rule-of-thumb concepts. Two experiments were performed. In the first experiment, the effects of hue, lightness and saturations on apparent distance were measured in a laboratory setting using a special depth perception apparatus with painted test materials. Results indicated that lightness alone could cause differences in apparent distance of as much as 5 to 17 percent depending upon the hue. Hue effects varied between 9 and 19 percent for saturated colors, and between 2 and 3 percent for relatively unsaturated colors, with red and yellow appearing to "advance" relative to green and blue. While a saturated red appeared 15 percent closer, on the average, than an unsaturated red, no reliable or consistent differences were found for the other hues. In the second experiment, a room shell, 12 by 22 ft. with movable end walls, was constructed to test for effects in a more realistic applied situation. Seven movable wall panels, each a different color, were adjusted by each of 64 male and 64 female observers to appear equally distant from a standard gray panel at the opposite end of the room. The observers also listed these colors in order of preference, and in order from most to least "advancing" as they had appeared during the experiment. The following



resulted: (1) With respect to hue, yellow was the most "advancing" followed by red, green, white, gray, blue and black. (2) With respect to lightness, the order from most to least "advancing" was white, light gray, and black. (3) With respect to saturation, all saturated colors appeared closer than the medium gray standard. (4) There was no significant effect due to sex. (5) There was some correlation between color preferences and the experimental settings but no correlation between the order of apparent distance in the questionnaire and in the experimental setting. The following conclusions were offered. Color does affect apparent distance, but only to a small degree—no more than 3 percent at most. Either the effects attributed to brightness on apparent distance have generally been in error, or the effect varies with the situation, or the effect is so small that it is unimportant. The rule-of-thumb about "warm colors advancing and cool colors receding" is very likely incorrect. The effect of color on apparent room size should be a minor consideration.

**Helson, H. and Lansford, T. THE ROLE OF SPECTRAL ENERGY OF SOURCE AND BACKGROUND COLOR IN THE PLEASANTNESS OF OBJECT COLORS. *Applied Optics* 9(7), 1513.**

Effects of spectral energy distributions of sources and colors of backgrounds on the pleasantness of object colors were determined by having 5 men and 5 women rate 125 object colors on 25 colored backgrounds in 5 sources of illumination. In addition, foods and complexions were rated in the same sources. All main effects were found to be highly significant statistically. While lightness and chromatic contrasts of object and background were more important than quality of illuminants, the latter were very important in the case of some object and background color combinations. Differences between the sexes were highly significant in that men tended to prefer cool source, object, and background colors, women the warm colors. The best colors for backgrounds had either low chroma and high reflectance (the pastel colors), or low chroma and low reflectance. The most important single factor determining the pleasantness of color combinations was

are bound to fail to some extent or other. A summary of the generally accepted principles are given instead. They are: (1) Color harmony results from the juxtaposition of colors selected according to an orderly plan that can be recognized and emotionally appreciated. (2) Of two similar sequences of color, that one will be most harmonious which is most familiar to the observer. (3) Any group of colors will be harmonious if, and to the degree that, the colors have a common aspect or quality. (4) Color harmony can only be achieved by a combination of colors whose plan of selection is unambiguously evident.

Judd, D.B. COLOR HARMONY: AN ANNOTATED  
1950 BIBLIOGRAPHY. U.S. Dept. Of Commerce, National Bureau of Standards, Washington, D.C., Letter Circular LC 987.

Summaries of the conclusions of 44 works on the subject of color harmony are included in this bibliography. Only one of these works, a study by Allen and Guilford, has been abstracted separately; this is in order to describe the particular experiment.

Judd, D.B. and Wysecki, G. COLOR IN BUSINESS, SCIENCE,  
1963 AND INDUSTRY. (Object-Color Perception in Complicated Scenes). New York: John Wiley & Sons, Second Edition, 331-41.

The fact that the eye constantly scans a scene, fixating upon various objects or patches of light in so doing, is of great importance in perceiving colors. Experiments which illustrate the phenomena of successive contrast, simultaneous contrast, color constancy, and memory color are described. Two-primary color projections provide a way of demonstrating object-color perceptions in complicated scenes in which all the above phenomena may be observed to come into play simultaneously. Judd's empirical formulas predict in a general way most object-color perceptions in a given simple scene.

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Kahler, W.H. and Meacham, J.A. CORRELATION OF  
1948 BRIGHTNESS RATIOS AND DECORATION. *Illuminating Engineering*, 43(2), 175-93.

The purpose of this paper is to show how the fundamentals of good decoration agree or disagree with brightness ratio recommendations of the Illuminating Engineering Society. The paper is confined primarily to commercial interiors where critical and prolonged seeing tasks are involved. The importance of contrast in color and brightness to give pattern and form and thus establish the character of design is recognized and the monotonous and uninteresting results of efforts to reduce brightness ratios to approximately unity are noted. The difficulties encountered in selecting color for large areas using small color chips is explained. The psychological effect of color in its ability to bring about an apparent alteration in the size and proportions of a room is discussed. The studies included in this paper indicate in general that good decorative schemes can be executed with low brightness ratios, but not with ratios of unity because some contrast is necessary to give character and interest to a room interior.

Logan, H.L. INTERIORS: LIGHT AND COLOR. *Architectural and Engineering News*, (9), 38-43.  
1964

How a good interior environment may be achieved through an adequately designed interplay of color and light is described. The principle of indifference, color reflection factors and good light balance, illuminant versus object color, good versus bad footcandles, and the proven influences of light on health are discussed. A chart of surround colors shows 54 low-response colors arranged according to reflection factors and divided into warm and cool color groups.

Logan, H.L. COLOR IN SEEING. *Illuminating Engineering*, 58(8),  
1963 553-59.

Brightness and color patterns, encountered peripherally, automatically cue or miscue people, generate desirable or

undesirable emotional responses, and influence safety and health. Rigid rules used by lighting engineers have produced bland environments with resulting complaints that lighting level recommendations are too high. Color can be used to balance the distribution of light in the field of view. For applications where critical seeing tasks are involved, 55 percent of the light should reach the observer from above, and 45 percent from below. This can be achieved with direct lighting, adequate optical control, and color control to obtain the required reflectances.

Metcalfe, J.T. THE PLEASANTNESS OF BRIGHTNESS  
1927 COMBINATIONS. *American Journal of Psychology*, 38(4),  
607-23.

This investigation was a study of aesthetic reactions to certain colorless stimulus-objects, each one consisting of two shades of different intensity. Twelve men and 12 women expressed affective judgments in paired comparisons of 190 stimulus-objects displaying various tones of gray. The results indicated: (1) The subjects in general preferred combinations of two grays which represented a relatively small degree of brightness difference. Combinations of gray with black or with white were in general less preferred, and combinations of black and white least preferred. (2) The pleasantness of the single component shades is an important factor in determining the pleasantness of a combination. (3) No sex difference appeared.

Murray, D.C. and Deabler, H.L. COLORS AND MOOD-TONES.  
1937 *Journal of Applied Psychology*, 41(5), 279-83.

To obtain a cross-regional comparison with Wexner's study, 25 subjects were presented with eight stimulus colors and a list of eleven moods and asked to pick a color to go with each mood. In nine out of the eleven mood-tones, chi squares revealed highly significant differences between the groups tested in different parts of the country. Socioeconomic differences appeared to be more important in causing differential choice of colors to go with mood-tones than were either mental health differences or differences in geographical regions within the country.

Newhall, S.M. WARMTH AND COOLNESS OF COLORS. *The*  
1941 *Psychological Record*, 4(15), 198-212.

The purpose of the study was to secure estimates of apparent warmth and coolness from numerous closely stepped samples of color, and to secure evidence that the apparent warmth and coolness are due to hue association with chromatic thermal objects. Two hundred ninety-seven subjects, 184 male and 113 female, 191 white and 106 negro, chose the warmest and the coolest color from fifty surface color samples known as the Munsell "Maxima." They also reported such reasons for their selections as occurred to them. The results indicated the following: (1) The reds and yellow reds are thermally "warmest" hues. (2) The cool hues range from yellow through green and blue to purple with no unequivocal "coolest" mode. (3) The above results seem to be essentially independent of both sex and race. (4) The apparently warm and cool colors and the perceptually warm and cool objects, reported by the subjects as associated with them, are distributed in similar fashion. (5) There is overlapping of warm and cool colors in the yellow and the purple-blue regions, and this overlapping may be due in part to conflicting associations.

Newhall, S.M., Burnham, R.W., and Evans, R.M. INFLUENCE OF  
1959 SHADOW QUALITY ON COLOR APPEARANCE. *Journal*  
*of the Optical Society of America*, 49(9), 909.

Shadows of skylight quality and of daylight quality were cast upon various test samples. The color appearance of a test sample, both as shadowed and unshadowed, was matched by three observers adjusting the field of a visual colorimeter. Only the skylight shadow evoked any trend in hue, and this was toward the blue. But both shadows produced systematic losses in saturation and lightness. Still none of these perceptual changes was as great as the corresponding colorimetric change in the test stimulus would suggest; in other words, considerable color constancy was associated with both shadows. The difference in effect between the two kinds of shadows was appreciable as evaluated in Munsell hue, but seemed almost negligible as regards value and

chroma. These results refer to the attention-directed experimental observations; more casual viewing presumably would result in more constancy effect and even less differential effect.

Pillsbury, W.B. and Schaefer, B.R. A NOTE ON "ADVANCING"  
1937 AND "RETREATING" COLORS. *The American Journal of Psychology*, 49(1), 126-30.

The apparent nearness of red as compared with blue was studied by means of an apparatus which compensated the size of a red and a blue light at different distances to give the same retinal image. Fifteen observers made judgments as to which of the lights were nearest under three settings. The blue seemed nearer than the red for 11 of the 15 observers.

Schaie, K.W. SCALING THE ASSOCIATION BETWEEN COLORS  
1961 AND MOOD-TONES. *The American Journal of Psychology*, 74(2), 266-73.

The association between 11 adjectival mood-descriptions as well as the term "pleasant" with 10 colors was scaled by means of a variation of the constant-sum method using the constant-stimulus model. Scale-values were obtained for each color on each mood-tone from two groups of judges, one of which repeated judgments after a three-month interval. Scale-values showed reasonably good replication from one group of raters to the other and for the same group over time. Low and high scale-values were well replicated but many changes of position occurred for intermediate values. Some colors were found to be associated with several mood-tones and some mood-tones were associated with more than one color. Intercorrelations of scale-values between colors and mood-tones were factored and four factors were identified. These factors were interpreted as the dimensions of activity-passivity, quality of emotional tone, mood-strength and emotional control. Previous findings of associative relations between colors and mood-tones as well as some of their semantic dimensions were confirmed. A

methodology producing reasonably stable scales is described. Findings of scalar consistencies as well as a wide range of individual differences suggest the desirability of future normative studies.

**Taylor, I.L. and Sumner, F.C. ACTUAL BRIGHTNESS AND  
1945 DISTANCE OF INDIVIDUAL COLORS WHEN THEIR  
APPARENT DISTANCE IS HELD CONSTANT. *The Journal  
of Psychology*, 19, 79-85.**

It was proposed in this study to hold constant the apparent distance of various colors and thus to determine quantitatively the relationship of the actual distances of these colors to the individual brightness of the respective colors as measured in terms of reflected light from a constant distance. Seven colors (Hering's) were given Munsell designations for hue, value and chroma, and brightness measurements were taken. Five females and six males attempted to match distances of the different colors in a Howard and Dohleman's depth perception apparatus. It was concluded that the physical measurements of the brightness of the respective colors were related in a highly positive way with the errors of distance estimation for the colors. The light colors appeared nearer than the dark colors.

**Tinker, M.A. LIGHTING AND COLOR. In A Survey Report on  
1949 Human Factors in Undersea Warfare, Washington: National  
Research Council, Committee on Undersea Warfare, 357-74.**

Certain colors and tints of colors are preferred over other colors and tints. Some colors carry the meaning of warmth, others appear cool. Some are exciting, others subduing. Attention must be given to the reflection factor of the color, since much of the usable illumination in an enclosed space should come from reflection of light from the ceiling, walls and furnishings. On large areas saturated colors and any paint of low reflectance should be avoided. Tints of colors should be used. Table tops should reflect 30 to 40 percent of incident light. Deck spaces should reflect 20 to 25 percent. Variety of color in decoration is desirable.

Tinker, M.A. EFFECT OF STIMULUS-TEXTURE UPON  
1938 APPARENT WARMTH AND AFFECTIVE VALUE OF  
COLORS. *The American Journal of Psychology*, 51(3),  
532-5.

The effect of stimulus-texture upon apparent warmth and upon affective value of colors in two situations where the surface-texture is considerably different was investigated. The subjects were 50 men and 50 women between the ages of 17 and 30 years, mostly university students. Rankings were made according to apparent warmth and to preference of colors of cloth and paper samples. The results of the experiment produced the following conclusions. (1) Rankings for apparent warmth and for affective value of color can be established with a high degree of consistency. (2) Surface texture, as represented by coated paper versus cloth, has little or no effect upon apparent warmth or affective value of colors. (3) Warm colors tend to be preferred over cool colors or achromatic stimuli. (4) The ranking for apparent warmth of colors by men is practically identical to that for women. There is, however, a slight tendency toward sex differences in color preferences.

Washburn, M.F., McLean, K.G., and Dodge, A. THE EFFECT OF  
1934 AREA ON THE PLEASANTNESS AND UNPLEASANT-  
NESS OF COLORS. *American Journal of Psychology*, 46(4),  
638-40.

In order to determine the effect of area on the pleasantness and unpleasantness of colors, 82 observers expressed their judgment about 18 colors, each presented on Bradley colored paper squares 5 cm. and 25 cm. on a side. A marked tendency was found to prefer the small areas to the larger areas of the dark yellow and orange papers; this preference was ascribed to unpleasant associations. The affective values of the other colors showed no reliable differences between the smaller and larger areas.



Washburn, M.F., Haight, D. and Regensburg, J. THE RELATION  
1921 OF THE PLEASANTNESS OF COLOR COMBINATIONS  
TO THAT OF THE COLORS SEEN SINGLY. *American  
Journal of Psychology*, 32(1), 145-6.

The design of these experiments was to see whether the principle that the pleasantness of a color combination varies directly as that of its components, as concluded by Geissler, would hold good when absolute rather than comparative judgments of affective value were made. Two hundred eleven women college students expressed their judgment of the degree of pleasantness of colors and combinations of colors presented by 3 cm. squares of the Bradley series pasted on white cards 2½ by 3 inches. Shades and tints were used as well as saturated colors. The study confirmed that the unpleasantness or pleasantness of a color combination is derived not merely from summation of the affective tones of its components, but from another factor dependent on the combination itself.

Wexner, L.B. THE DEGREE TO WHICH COLORS (HUES) ARE  
1959 ASSOCIATED WITH MOOD-TONES. *The Journal of  
Applied Psychology*, 38(6), 432-5.

In an attempt to determine to what degree colors (hues) are associated with mood-tones 94 subjects were presented with eight stimulus colors and eleven mood words. It was found that for each mood-tone certain colors were chosen to "go with" that mood-tone significantly more often than the remaining colors. Several possibilities for this were given, such as the influence of cultural, biological, and learning factors.

## Chapter VI

### SEATING COMFORT

This chapter includes entries and abstracts of studies pertaining to the provision of comfort and posture control for sitting. It has been assembled primarily as a reference aid to designers concerned with the development and evaluation of proper body support in seating.

Much of the literature on seating design has been generated by the transportation industry out of concern for the comfort and safety of their passengers and operators. The military has also made a contribution in the area of body support and restraint for the operation of aircraft. The subject of comfort and posture control for seating has been approached from anthropometrical, physiological, behavioral and anthropological viewpoints. Anthropometric data specific to sitting posture is conveniently summarized from various sources in a table of design recommendations in *The Human Body in Equipment Design* by Damon, Stoudt and McFarland (1966). Comprehensive studies of sitting measurements may be found in *A Survey of Seating* by Hooten (1945), *Standing and Sitting Posture* by Akerblom (1948), and *Basic Design Measurements for Seating* by Ridder (1959). The physiological study, "Alterations of the Lumbar Curve Related to Posture and Seating" by Keegan (1953); the behavioral study, "Behavior, Body Mechanics and Discomfort" by Branton (1969); and the anthropological study, "The Anthropology of Posture" by Hewes (1957) are also key works in their respective areas.

For information relating to furniture design in general, a quarterly publication of the Furniture Technical File at North Carolina State University, *The Furniture Index*, is recommended. It includes abstracts of technical writings about materials, engineering, production, management and other aspects of the furniture industry.

An excellent review of European literature on sitting posture for office work is *Ergonomics in the Design of Office Furniture* by Kroemer and Robinette, published in 1968 by the Aerospace Medical Research Laboratories at Wright-Patterson Air Force Base.

## SEATING COMFORT

Akerblom, Bengt. CHAIRS AND SITTING. in Floyd, W. F. and  
1954 Welford, A. T., (Eds.), *Symposium on Human Factors in  
Equipment Design*. London: H. K. Lewis & Co.

Designers' assumptions that the thighs should rest firmly on the seat so as to increase the weight-bearing area and distribute the pressure from the upper part of the body are wrong. To avoid undue pressure on the sensitive soft parts of the thigh, the chair must be so constructed that the weight of the body is borne on the ischial tuberosities. Measurements of the length of the lower leg from the floor to the bend of the knee taken from 363 female and 295 male Swedish subjects in a seated position indicate that nearly 3 out of 4 Swedes sit on seats which are too high (45+ cm) and therefore uncomfortable. A similar group of subjects provided measurements of the thigh to the back rest of the chair showing that a depth of 45-47 cm is permissible. A slope of 5-7 degrees in the seat is suggested by a Birmingham Anthropometric Survey (1948). The backrest should encourage position changes and support the lumbar region. Experience of the author suggests that a back slope of 115 degrees is best for ordinary chairs. In order to support the entire lumbar spine, the support should begin at the sacrum which is 20 cm above the seat. An ideal chair is illustrated.

**Akerblom, Bengt. STANDING AND SITTING POSTURE. *Nordiska*  
1948 *Bokhandeln*, Stockholm.**

This research took its origin from the observation that ordinary chairs and other simple seats are clearly unnecessarily uncomfortable. The object of the investigation was to explore the prerequisites for various comfortable sitting positions. In order to determine what positions might be considered resting positions, it was necessary to study the so-called restful standing position. Thus the work consists of three relatively loosely connected parts: 1) concerning the special functions of the interarcuate ligaments; 2) concerning the mechanics of the standing position, including the determination of the position of the sagittal plane of the center of gravity of the body; 3) concerning the mechanics of the sitting position and the conclusions of importance for the construction of seating. Techniques of electromyography and radiography were used. Three basic seating positions, insofar as the back is concerned, in which the muscles can relax are identified. The main conclusion drawn from the study is that seats should be designed to be lower, so low that a person's thighs are free or almost free from them. A 40 cm seat height is recommended. Other recommendations are made regarding seat depth, back rest support and softness of seats.

**Anderson, D. and Brooks, M. J. SEATING THE DRIVER. *Design*,  
1961 154, (Great Britain), 52-57.**

For the purpose of improving design for safety and comfort of the vehicle driver, this investigation included a comparison of certain dimensions of four given cars to ascertain how and where they differed. Data from the investigation indicated shortcomings in each of the designs insofar as concerned accommodation of the great diversity of drivers' body dimensions.

**Anonymous. PRE-LOADING SYSTEM ADJUSTS  
1955 TORSION-SUSPENDED SEAT. *Design News*, 10(15), 26-27.**

A new seat designed to isolate shock and vibration so as to avoid back and kidney damage to truck, bus, and tractor

drivers is described. Two rubber blocks used as torsion springs are preloaded according to the weight of the person occupying the seat, the adjustment ranging from 100 to 275 pounds. The seat has a natural frequency below that of the vehicle, a design feature that prevents vibrations from reaching the driver. The seat can be adjusted for depth, height, back angle, cruising angle, and for nine positions of fore and aft movement. The frame is tubular steel and the cushions are foam rubber. The seat is estimated to accommodate 99% of all drivers. The Bostrom Company of Milwaukee designed the seat, which is designated the "Level Ride 80."

**Barkla, D. M. CHAIR ANGLES, DURATION OF SITTING, AND  
1964 COMFORT RATINGS. *Ergonomics*, 7(3), 297-304.**

In an experiment with young male subjects, comfort ratings made after 30 minutes' sitting permitted discrimination between chairs that were substantially alike except for the rake of the back. Successive ratings made by the same subjects showed no order effects. But ratings made after 5 minutes' sitting did not permit the same discrimination, and were distorted by an order effect.

**Barkla, D. M. THE ESTIMATION OF BODY MEASUREMENTS OF  
1961 BRITISH POPULATION IN RELATION TO SEAT DESIGN.  
*Ergonomics*, 4(2), 123-32.**

Reports of surveys of human measurements are not always easily accessible, and their information about dimensions relevant to seat design is often mixed up with other matter. This paper brings together the principal published information on relevant dimensions. Most of the populations surveyed are not themselves important to British designers, but estimates of the measurements of young British adults are derived from the published material.

**Beckett, L.C. PASSENGER SEAT DESIGN AS APPLIED TO THE  
1959 CONVAIR 880. American Society of Mechanical Engineers,  
Reprint No. 59-AV-20.**

A case history of the development of the Convair 880 Pas-

senger Seat, from inception to design completion, including discussion of comfort, styling, safety, and lightweight durability. Basic seat-frame construction, special features, and the test program outline are also discussed.

**Bennett, E. PRODUCT DESIGN EVALUATION THROUGH THE  
1963 MULTIPLE FORCED-CHOICE RANKING OF  
SUBJECTIVE FEELINGS, (Study 3: The Feeling of  
Comfort). In Bennett, E., Degan, J., and Spiegel, J. *Human  
Factors in Technology*. New York: McGraw-Hill, 543-555.**

Feelings of physiological comfort as they are influenced by seat design were assessed by subjects' evaluation of relative comfort in various areas patterned across the dorsal portion of the body. Eight judgments were obtained from four subjects at ½ hour intervals for a total sitting period of 3½ hours in each of three seats. The results were averaged and compared.

**Berg, J. A. POSTURE AND SEDENTARY MAN. Delivered for  
1968 A.C.C.O. Convention, San Francisco.**

The anatomy of the spine and pelvis is discussed in relation to the dynamics involved in seated posture. Posture is related to concepts of seating design. Changes in posture are extremely important in order to delay fatigue. During prolonged sitting without posture change, conditions of stasis and thrombosis may occur. New concepts of seating such as the dual platform seat may prevent restriction in the circulatory system.

**Berg, J. A. THE SELF-ALIGNING SEAT. Jebco, Inc., San Marino,  
1959 California**

A yielding chair seat, such as the self-aligning seat described in this monograph, creates an exercise effect on the body. The self-aligning seat was developed as a result of knowledge and experience gained through the use of an Orthostructurometer, an instrument used in evaluating and treating persons presenting problems in body mechanics. The seat is characterized by a dual platform with four soft springs under each half, and a fulcrum under the tuberosities of each

half such that it can move under the sitter. Results of a study by the Human Performance Laboratory at the University of California at Los Angeles, which used the seat in investigating problems of sedentary man, are included.

**Branton, P. BEHAVIOUR, BODY MECHANICS AND  
1969 DISCOMFORT. *Ergonomics*, 12(2), 316-27.**

This survey of problems raised by behavioural observation in relation to sitting comfort research attempted to show their possible complexity. It suggested that sitters can provide information about seats not only by verbal judgments but also through other channels, such as performance on concurrent tasks. Observation of sitters may be used in addition to indicate the limits of tolerance to discomfort. Sitting behaviour could be regarded as the operation of a balance between needs for physical stability and for environmental and intrinsic stimulation. The relationship between a seat and the sitter's discomfort is not thought to be direct because his tolerance may be influenced by an overriding but fluctuating motivation to sit. A more direct relationship appears to exist between a seat and the sitting posture taken up in it. Thus seats may cause postures and a closer analysis of postural mechanics may add to understanding about the quality of seats.

**Branton, P. AN EVALUATION OF TRAIN SEATS BY  
1967 OBSERVATION OF SITTING BEHAVIOUR. *Ergonomics*,  
10(1), 35-51.**

To establish a naturalistic basis for the evaluation of train seats, the sitting behaviour of train travelers was recorded by two techniques. First, 5000 observations of sitting postures were made during five-hour journeys using a rapid coding method. Second, time-lapse films were taken of a selected sample of 18 subjects traveling on the same route. By using the same code it was possible to compare the results of the two techniques, and high correlations between them were found. Two types of seat were studied and significant differences in behaviour were found. Frequency of occurrence, duration and sequences of postures were used to arrive at quantitative comparisons.



Burandt, U. and Grandjean, E. SITTING HABITS OF OFFICE  
1963 EMPLOYEES. *Ergonomics*, 6(4), 217-28.

Postural habits deviating from orthopaedic and anthropometric considerations are investigated to determine comfort criteria. The investigation comprised a survey of complaints and the measuring of body dimensions and seat and table heights as well as 4920 observations of occupations and sitting postures. Results of the study of chair seat heights performed on 68 subjects involved in office work failed to support the recommendations of Akerblom and Keegan which favor low (38-41cm) seat heights. Forty-two to forty-seven cm heights were found to be most convenient, optimum posture of the upper body being ensured by the fixed distance of the table above the chair seat (28 cm). The use of back rests is discussed.

Damon, A., Stoudt, H.W. and McFarland, R.A. THE HUMAN BODY  
1966 IN EQUIPMENT DESIGN. "The Design of Seats and the Seated Workspace." Cambridge, Mass.: Harvard University Press, 311-18.

Data from a number of studies by other authors is compiled in a table which contains recommendations for nine seat dimensions grouped by kind of seat. The seats are discussed along with workspace dimensions and other characteristics, with recommended values for the general population based on anthropometric data.

Dempsey, C. A. BODY SUPPORT/RESTRAINT. *Product*  
1962 *Engineering* 33(4), 106-17.

Body support is defined as a mechanical device that supports the body in a normal 1-g environment. Body restraint is a mechanism that is opposite to body support and prevents the body from displacing. Physiological fatigue in the seated position is characterized by compression loading of the flesh which prevents flow of the blood through the capillaries; stagnation of the entire physiological system because of

inactivity of major body segments and mal-accommodation to the location and arrangement of controls in the workspace. A "buttockscope" was designed for continuous display of pressure patterns on any part of the body. Restraint mechanisms are discussed in regard to the design of high-acceleration seats.

Diffrient, N. DESIGN WITH BACKBONE. *Industrial Design*, (10) 1970 44-7.

Henry Dreyfuss Associates undertook the design of a new type of aircraft chair for American Airlines' Boeing 747 and the Douglas DC-10. Besides the goal of designing a good-looking, functional seat, the designers wanted to understand what comprises seating comfort. To gain information about how people are affected by the shape of a chair and the softness of cushions, a sitting machine was constructed which could be adjusted to any contour and cushion density. Contour support, recline angles, armrest positions and seat heights could be adjusted. Small probes determined where a body came to rest within the depth of the cushion, allowing a grid diagram of the body form to be obtained. Measurements were obtained for a range of body sizes from small female to large heavy male. Data from the experiment are not included in the article. Primary comfort areas of seat design are summarized.

Ellis, D. S. SPEED OF MANIPULATIVE PERFORMANCE AS A FUNCTION OF WORK-SURFACE HEIGHT. *Journal of Applied Psychology*, 35, 289-96. 1951

An experiment was performed to determine the relationship between work-surface height and speed of manipulative performance of a simple block-turning task. Subjects were 48 male college students who performed the task at six levels of work-surface height, ranging from a minimum average height of 25.9 in. to a maximum average height of 52.7 in. A Latin-square experimental design was used, in which each subject worked at each work-surface height for a three-minute trial. Analysis of the data yielded the following results: 1) Statistically significant variations in speed of

manipulative performance were associated with variations in work-surface height. Maximum performance occurred at an average height of 42.0 in., which corresponds to a setting approximately 3 in below the elbow. Significantly slower performance occurred at higher work-surface heights than at lower heights. 2) Significant variations in feelings and locus of muscular strain are associated with variations in work-surface height. An interpretation of the obtained results is offered on the assumption that muscular tension is the variable intervening between work-surface height and performance. The applicability of the construct of reactive inhibition to the data is also noted, and an experiment is suggested to test an hypothesis stemming from the use of this construct. While the results are considered as having only minor immediate practical value for problems of industrial equipment design, they are viewed as indicating that work-surface height is an equipment design variable which is worthy of further investigation.

**Floyd, W. F. and Roberts, D. F. ANATOMICAL AND  
1958 PHYSIOLOGICAL PRINCIPLES IN CHAIR AND TABLE  
DESIGN. *Ergonomics*, 2(1), 1-16.**

General principles derived from anatomical, physiological and clinical studies of movement and posture may be applied to the design of furniture, but an understanding of these principles is important. This paper attempts to provide such an understanding so that anthropometric data can be used critically in relation to determining dimensions and shape of chairs and tables for office and general domestic use.

**Floyd, W. F. and Silver, P. H. S. THE FUNCTION OF THE  
1955 ERECTORES SPINAE MUSCLES IN CERTAIN  
MOVEMENTS AND POSTURES IN MAN. *J. Physiol.*, 129,  
184-203.**

The action of the erector spinae muscles in the lumbar region was studied in 150 human subjects by electromyographic techniques with surface and concentric needle electrodes. Posture was recorded by photography, by measurement of the pelvic inclination and by radiography

of the lumbar and vertebrae and sacrum. Observations of standing and sitting postures indicate that relaxation of the erectores spinae muscles is related to the degree of flexion of the vertebral column but is independent of flexion of the hip joint.

Floyd, W. F. and Ward, J. S. ANTHROPOMETRIC AND  
1969 PHYSIOLOGICAL CONSIDERATIONS IN SCHOOL,  
OFFICE AND FACTORY SEATING. *Ergonomics*, 12(2),  
132-9.

Anthropometric data and analyses of the behaviour of schoolchildren with the multimoment technique during lessons are the basis for the considerations of the problems of school, office and factory seats. Characteristic postures of schoolchildren are: trunk straight, shoulders straight, legs straight, trunk supported by arms, and backrest used. The backrest was used about 50 percent of the time in traditional furniture, and about 60 percent of the time with new furniture. The most frequent sitting behaviour was a desk-supported posture. With one school child myograms were recorded in the characteristic sitting posture. The lowest electrical activity occurred when the backrest was used.

Garrow, C. and Wooller, J. THE USE OF SHEEPSKIN COVERS  
1970 ON VEHICLE SEATS. *Ergonomics*, 13(2), 255-63.

Driver preference for sheepskin car seat covers has been compared with their preference for other types of car seat overlays by the pair comparison method. The trials were carried out by professional drivers in several types of motor cars and trucks. Overlays were found to improve the comfort of motor car and truck seats. Woored sheepskins were more comfortable in a popular motor car and in trucks than the other types of overlay tested. In an expensive car with more luxurious seating, they did not add to the comfort of the seat.

Grandjean, E., Boni, A. and Kretzschmar, H. THE DEVELOPMENT  
1969 OF A REST CHAIR PROFILE FOR HEALTHY AND  
NOTALGIC PEOPLE. *Ergonomics*, 12(2), 307-15.

Various seat profiles were tested with healthy and notalgic persons using a "seating machine" which made it possible to give the seat surface and backrest of a test chair any profile. After the experiments these persons were given a questionnaire in which they had to report their subjective sensations in the various parts of the body and their evaluation of various angles and dimensions. Optimum values of seat inclination and backrest inclination were determined in one experiment conducted with 52 healthy persons, and in two further series of tests with 38 and 68 notalgic persons who had all been treated for disc derangements in the region of the lower lumbar spine.

**Hanff, G.E. INTEGRATION OF MAXIMUM COMFORT INTO THE  
1959 ELECTRA PASSENGER SEATS.** American Society of Mechanical Engineers, Reprint No. 59-AV-20.

An adjustable plywood mockup chair was constructed using anthropometric data covering the range of basic human measurements to establish adjustment limits. Adjustments included seat angle, back recline, arm height, foot-rest location, floor position, and seat-back clearance. This chair was used to determine the dimensions and contours necessary for optimum comfort and to verify various features of physiological analysis. X-ray profiles were used extensively to study skeletal positioning and soft tissue deformation in various positions. Finally, in conjunction with the optimum configuration indicated by the studies in a final mockup chair, full-size body x-ray profiles of a man and a woman were made to show the overall effect.

**Hertzberg, H. T. E. DYNAMIC ANTHROPOMETRY OF WORKING  
1960 POSITIONS.** *Human Factors*, 2, 147-55.

This paper provides a review of the principles and procedures of workspace design for engineers. It emphasizes that human body size, anthropometry, muscle force capability, and biomechanics are all essential for the efficient sizing of equipment. The proper method of workspace design, the "design limits concept," is described, and the fallacy of the

"average man" concept is demonstrated. General methods of gathering body size and strength data are outlined, and major information sources noted. The author's ideas on human muscle strength in the weightless state are included.

Hertzberg, H. T. E. SEAT COMFORT. Annotated Bibliography of 1958 Applied Physical Anthropology in Human Engineering, Appendix I. (Wright Air Devel. Center, Wright Patterson Air Force Base, WASDC TR 56-30, ASTIA Doc. AD-155622). 297-300.

Discomfort and fatigue make a man inefficient and prone to mistakes. The Air Force has therefore actively sought to reduce discomfort in its aircrew accommodations, especially in seating. One cannot "provide comfort" in a seat design; one can only "eliminate sources of discomfort." The length of time that a sample of subjects can endure a given position is so far the simplest, though not the only way assessing the discomfort resulting from it. One must specify the expected duration of occupancy in evaluating a given seat. The tests started with a seat and back 17 in. wide, seat at 6 degrees above horizontal, back at 13 degrees past vertical, seat reference point supported 8.5 in. above the heel rest (floor). In the standard seat, the seat pan and back were made flat, while a contoured metal seating surface was also used. Seating conditions were varied by using 1 in. foam rubber pad on each of the seats. Although the full program was never completed, it was found in preliminary tests that the standard seat made the test subjects uncomfortable in about 1½ to 2 hours, the contoured seat with 1 in. pad in about 4-5 hours. It is the opinion of the author that the adequately-cushioned, contoured seat is superior to a flat surface for persons who cannot frequently leave the seat. That one can more easily shift from one buttock to the other on a flat surface than on a contoured surface is true; but it involves the assumption that the buttock thereby relieved of pressure will completely recover during the period of relief. Experience has shown, however, that there is not a complete recovery, and the net result over a period of hours, is a slowly increasing discomfort throughout the test. On a contoured surface, especially with cushion, the tissues

surrounding the ischial tuberosities absorb an appreciable portion of the load, thereby reducing the discomfort in the compressed tissues.

Hertzberg, H. T. E. SOME CONTRIBUTIONS OF APPLIED  
1955 PHYSICAL ANTHROPOLOGY TO HUMAN  
ENGINEERING. *Annals of the New York Academy of  
Sciences*, 63(4), 616-629.

One of three examples of applied physical anthropology presented in this paper concerns "What happens to the buttocks when we sit on them". Reference is made to the work of Lay and Fisher who measured buttock pressures by means of their "Universal Test Seat". Two devices for buttock measurement are described, a "pressure measuring blanket" and "C-Ray Pediscope". The pediscope gives the distance between the tuberosities, the angle between the tuberosities, the area of the tuberosity for a given seating position, and the location of the tuberosities within the seating area. The pressure measuring blanket gives the approximate pressure under any part of the buttock area. The data collected by means of these devices will be used as an aid in further developing the Dempsey-Morrison type dynamic cushion which has cut-outs for the tuberosities.

Hewes, G.W. THE ANTHROPOLOGY OF POSTURE, *Scientific  
1957 American*, 192(2), 123-32.

The ways in which we sit, kneel or stand are determined not only by the human anatomy but also by culture. By observing anthropologists' photographs, as well as paintings and sculpture from all ages, the author has made a set of world maps showing the distribution of various static postures. Also illustrated are a sampling of posture types from the classification scheme of the author. Many of the posture types illustrated are common sitting positions.

Hooton, E. A. A SURVEY IN SEATING. Gardner, Mass.:  
1945 Heywood-Wakefield Co.

A group of 3867 American male and female subjects over the age of 17 provided measurements of weight, stature, seat

length, seat height, back height, elbow height, hip breadth and shoulder breadth. The measurements were taken by means of a special measuring chair and scale. The measurements were presented in the form of percentiles and correlations, shown in eleven tables in 21 scatter diagrams and one zoned diagram. Tentative chair design recommendations were made on the basis of these data. Further studies were undertaken to determine variations of spinal curvature in standing and sitting postures. Using a moldable lead rod in one instance, and sand impressions in another, it was concluded that the lumbar curve is diminished or completely flattened in sitting positions.

- Jones, F.P., Hanson, J.A. and Gray, F.E. HEAD BALANCE AND SITTING POSTURE II: THE ROLE OF THE STERNOMASTOID MUSCLE. *Journal of Psychology*, 52, 363-7.  
1961

Surface electromyography was used to study the role of the sternomastoid muscle in two erect sitting postures ("habitual" and "experimental"), which are sharply distinguished kinesthetically. Seven male students served as subjects for the experiment. In the experimental posture, which was brought about by changing the dynamic balance of the head while the posture was being assumed, the subjective feelings of weight and effort associated with the habitual posture were markedly reduced. Increased activity in the sternomastoid muscle, which seemed to be characteristic of the habitual posture, was not found in the experimental posture.

- Jones, F.P., Gray, F.E., Hanson, J.A. and Shoop, J.D. NECK-MUSCLE TENSION AND THE POSTURAL IMAGE. *Ergonomics* 4(2) 133-42.  
1961

The "postural images" of comfort, of correctness, and of height were studied in seven male subjects aged 16 to 21. The image was recorded photographically and electromyographically as the immediate response to a specific verbal stimulus. The response was quantified by measuring the angular relation of head to trunk and the change in electric potential of the sternocleidomastoid and upper trapezius muscles. Both sitting and standing postures were recorded. In addition, the effect on posture of effort (lifting), anticipation of movement, forced respiration, and standing on tip-toe was studied. The data were treated statistically.



Jones, F.P. and Gilley, F.M. Jr. HEAD-BALANCE AND SITTING  
1960 POSTURE: AN X-RAY ANALYSIS. *Journal of Psychology*,  
49, 289-93.

X-ray photography was used to study differences between two erect sitting postures which were sharply distinguished kinesthetically. Twenty male students served as subjects for the experiment. The two postures were found to differ significantly in four indices: the angle of head to horizon; the relative height of *sella turcica*; and the distance between the spines of the first two vertebrae. An hypothesis was advanced to explain the kinesthetic phenomenon in terms of forces acting on the head.

Jones, J. C. METHODS AND RESULTS OF SEATING RESEARCH.  
1969 *Ergonomics*, 12(2), 171-81.

Two methods of assessing sitting comfort are described. The first is a method of fitting trials, the results of which agree with Domey and McFarland's recommendations for car interior dimensions. The second method provides a measure of seat discomfort. Trained testers record sensations in parts of the body at intervals during a journey. The resulting discomfort index discriminates reliably between seats in different classes of vehicle but not between the seats in different makes of vehicle of the same class. The sum of the length and the height of the rectangle enclosing the sitter is proposed as another index of sitting comfort. This index is nearly constant for the front seats of three different makes of small car. The index for work-spaces determined by fitting trials is consistently larger than the index for small cars and for lecture theatre seating.

Kaplan, A. HUMAN FACTORS OF SEATING. *Industrial Design*.  
1962 Part I, 52-54.

Seating principles developed by Akerblom and others are restated. Three chairs, an Eames chair, a Thonet chair and the Ion chair are critiqued in order to illustrate the basic principles of human factors of seating.

Karvonen, M.J., Koskela, A. and Noro, L. PRELIMINARY REPORT  
1962 ON THE SITTING POSTURES OF SCHOOL  
CHILDREN. *Ergonomics*, 5(3), 471-7.

Young people attending school constitute in developed countries the biggest population group engaged in very similar work. Relatively little attention, however, has been attached to the ergonomic problems of school work. The paper gives recommendations drawn up on the basis of anthropometric and physiological studies for the dimensioning and designing of school equipment. In addition, a method was developed for studying how pupils use different pieces of furniture, including units designed on the basis of the results of the investigation, when sitting. The method gives conclusive indications of practical value on the furniture and also on the points which require attention in training pupils to sit correctly at the desk. This instruction is considered useful for working efficiency and health later in life. A bibliography supplements the list published by Floyd and Roberts (1958) on the ergonomics of tables and chairs.

Keegan, J.J. EVALUATION AND IMPROVEMENT OF SEATS. In-  
1962 *dustrial Medicine and Surgery*, 34(4), 137-48.

Medical knowledge of the cause of most postural low back discomfort and pain in degenerated lower lumbar intervertebral discs has permitted better analysis of the seating problem. Dimensions are given for comfortable seating which avoids flattening of the lumbar curve and permits needed change of position in the seat. These basic requirements for a comfortable and protective seat have been given percentage values to help in the evaluation of 29 seats in common use. These seats have been discussed and outlined in the figures presented, with an interrupted outline superimposed on each to indicate desirable improvement.

Keegan, J. J. ALTERATIONS OF THE LUMBAR CURVE RELATED  
1953 TO POSTURE AND SEATING. *Journal of Bone and Joint Surgery*, 35-A(3), 589-603.

One of the most common complaints of persons with low-back pain is inability to sit in comfort, with difficulty

in straightening the back or rising. This must represent some fundamental defect in our conception of the correct sitting position and in the design of seats and chairs. This article presents an analysis of the subject of seating in relation to back symptoms. The work is based on a clinical study of over 3,000 persons with low-back complaints, 1,504 of whom had been operated upon for herniation of a lower lumbar intervertebral disc, as well as on a special study of the alteration of the lumbar curve in various sitting and standing positions. The studies found the most common cause of low-back pain related to seating to be posterior protrusion or extrusion of lower lumbar intervertebral discs. The normal curve of the lumbar spine in an adult man is determined by maintenance of the trunk-thigh and the knee angles at approximately 135 degrees. The most important cause of low-back pain in sitting is decrease of the trunk-thigh angle and consequent flattening of the lumbar curve. The next most important cause of low-back pain in sitting is lack of primary back support over the vulnerable lower lumbar intervertebral discs. Added factors of comfort in seating are the shortness of the seat, a rounded narrow front border, an open space beneath for better positioning of the legs, and permissive change of position in the seat.

Kirk, N.S., Ward, J.S., Asprey, E., Baker, E. and Peacock, B. DIS-  
1969 CRIMINATION OF CHAIR SEAT HEIGHTS. *Ergonomics*,  
12(3), 403-12.

A study was undertaken to determine how well a small sample of British male and female subjects could discriminate between a standard seat set at a height of 43.18 cm and a comparison seat, the height of which was varied in 0.64 cm steps between 40.64 and 45.72 cm. The Method of Constant Stimuli was used to present the seats to the subjects. A Differential Threshold and the Point of Subjective Equality were calculated for each subject, on whom stature and lower leg measurements were taken. The main conclusion from this study is that individuals discriminate between seat heights extremely well.

Kohara, J. and Hoshi, A. FITTING THE SEAT TO THE  
1966 PASSENGER. *Industrial Design*, (11) 54-9.

Studies of seating comfort were undertaken for a number of Japanese auto makers and the Japan National Railways. The objective was to obtain a seat configuration which would maintain a previously determined basic posture form for comfortable seating and would take into consideration the materials used in making the seat. An experimental apparatus was constructed in which the elasticity of the seat spring, the inclination of the back rest, and the shape of the back rest could be changed. Posture and the distribution of pressure were found to be the important factors in determining the successful functioning of a vehicular seat. Elasticity of a chair seat is explained in terms of a three-layered construction of cushion.

Le Carpentier, E. F. EASY CHAIR DIMENSIONS FOR  
1969 COMFORT—A SUBJECTIVE APPROACH. *Ergonomics*,  
12(2), 328-37.

Eight easy chair dimensions were examined to determine for each the value which subjects preferred for comfort in two situations, reading and watching television. The dimensions were the height of the seat front from the floor, the seat depth, the angle of tilt of the seat, the seat to backrest angle, the rake of the backrest, the height of the armrests above the seat, and the position of a flat padded rectangular headrest. In the case of the first five of the above dimensions, a pair of additional values were determined representing the borderlines of comfort, or tolerance limits. A power driven adjustable chair controlled by the subject was used. Twenty subjects each sat in the chair for periods up to three hours, and at intervals adjusted each dimension to the level which by his judgment matched a written criterion of comfort supplied by the experimenter. The experimental design allowed trends in preference to be tested across subjects' sex, age and stature. Tests of correlation were carried out between the subjects' anthropometric measurements and their preference settings, and between the preference settings in different dimensions. The other results consist of distributions of the preferred settings and tolerance ranges

for each dimension. These results collectively suggest that easy chairs for use by the general population should be available in at least two models, differing in shape as well as in size.

**Lippert, S. DESIGNING FOR COMFORT IN AIRCRAFT SEATS.**  
1950 *Aeronautical Engineering Review*, (2) 39-41.

Selected dimensions are plotted against stature using data from Hooton and AAF-TR 5501, *Nude Dimensions*. Positional and dimensional information from several studies are combined to define the position in which optimum comfort of 90 percent of the traveling public can be achieved in a fixed seat. The dimensions arrived at for: height of seat above floor, length of seat from front to back, width of seat; included angle between bottom and back,  $105 \pm 2$  degrees; break in seat back, length of seat back, foot rest, clearance between shin and forward seat structure, inclination of seat and height of arm rest above seat. Cushions and pads are discussed in the context of comfort under conditions of gust loads and vibration. The problem of cushion ventilation is recognized.

**Lloyd, N.M. COMFORT CRITERIA FOR SEAT DESIGN.** *Automotive Industries* 123(11), 44-48.

Comfort requirements were investigated by the Henry Dreyfuss design team for the development of a mobile armchair for the Lockheed JetStar. Criteria were established for variations in body size, changes in position, body weight rests, lumbar support, support for the upper back, head and neck support, under-thigh compression, arm rest, and sufficient slope. X-ray studies were made of average-sized male and female subjects sitting in the mockup chair.

**Lundervold, A. ELECTROMYOGRAPHIC INVESTIGATIONS DURING SEDENTARY WORK, ESPECIALLY TYPEWRITING.** *The British Journal of Physical Medicine*, (2), 32-6.

The purpose of the study was to ascertain whether a change

in the sitting position or in the manner of working, especially in typewriting, could be recorded in electromyograms from the muscles examined, thus allowing conclusions to be drawn as to the sitting position and manner of work which demanded the least active use of the muscles. Forty-seven healthy subjects, 18 female and 29 male, ranging in age from 14 to 50 years were used. Both surface and needle electrodes were used. The investigation showed that the healthy persons who do not tense their muscles can sit comfortably and relax in many positions, and can even work in many different manners without a pronounced increase in the muscle power. Nervous subjects, on the other hand, do not relax completely in more than a few positions, and they can not change their individual optimal working positions without a markedly increased exertion of muscle power.

McFarland, R. A., Damon, A., and Stoudt, H. W.  
1958 ANTHROPOMETRY IN THE DESIGN OF THE DRIVER'S  
WORKSPACE. *American Journal of Physical Anthropology*,  
16(1), 1-23.

Since differences in human body size may have serious implications for comfort, efficiency and safety of vehicle drivers, the aim of the study was to outline methods whereby data on human body size could be incorporated into vehicular design. Presented are the 5th, 50th and 95th percentiles of 30 pertinent body dimensions of 360 commercial bus and truck drivers. Specific values are recommended for a sample of cab dimensions closely linked to human dimensions. A procedure is outlined for utilizing a mock-up, in conjunction with subjects of known size, to determine cab dimensions involving dynamic or functional human measurements. Finally, general aspects and principles of applied anthropometry are discussed.

Morris, C. W. ANATOMY AND STATISTICS AID DESIGN OF  
1947 PASSENGER SEATS. *Society of Automotive Engineers SAE  
Journal*, 55(9), 24-6.

Criteria for the design of an adjustable type of aircraft seat is determined from an elementary knowledge of anatomy

and reliance upon the data on anatomical variations gathered by Hooton. An outline of a passenger seat designed from this data is presented showing both relaxed and erect positions. A means for achieving seat tilt and elevation is discussed. Moveable arm rests are advocated in response to overcome complaints of passengers that their elbows "go to sleep" when the seat is reclining.

Murrell, K. F. H. DESIGN OF SEATING. In *Human Performance* 1965 in *Industry*. New York: Reinhold Publishing Corp., 143-53.

The author discusses the importance of correct design for seating. Principles of seating comfort and posture are explained, and anthropometric data is included. Reference is made to research studies in seating comfort by Akerblom, Hooton, and Lay and Fisher.

Nachemson, A. ELECTROMYOGRAPHIC STUDIES ON THE VERTEBRAL PORTION OF THE PSOAS MUSCLE WITH SPECIAL REFERENCE TO ITS STABILIZING FUNCTION OF THE LUMBAR SPINE. *Acta. orthop. Scandina.*, 37, 177-90.

Lumbar disc measurements *in vivo* have in the unsupported upright sitting and upright standing positions revealed that heavier loads rest on the middle lumbar discs than can be explained by gravitational forces alone. In these positions the anterior abdominal and the sacrospinalis muscles have been found relatively inactive in previous electromyographic studies. It has also previously been shown that the ligamentous lumbar spine essentially is an unstable rod which needs external force for stabilization. The present investigation seems to support the idea that the vertebral portion of the psoas muscle besides functioning as a hip flexor, also takes part in maintaining upright postures. By its activity it adds a compressive force to the lumbar spine, thus adding to the gravitational forces to which the lumbar discs are subjected.

**O'Connell, E.R. A NEW CONCEPT IN SEATING.** Presented to the  
1960 Greater Los Angeles Chapter, National Safety Council, Fleet  
Safety Division.

Part of a program conducted at the Human Performance Laboratory at the University of California, Los Angeles, to determine causes of fatigue experienced by people sitting quietly for long periods of time. This study examined physiological responses of healthy subjects sitting in a regular single platform chair seat and a dual platform self-aligning chair seat. The tests were physiological and psycho-motor in nature. The physiological tests included segmental plethysmography which measures the amount of foot swelling, and oxygen consumption to indicate energy costs of the task. The psycho-motor tests consisted of simulated driving of an automobile and a rotary pursuit task. Each subject sat four times in both the regular single platform type chair seat and the dual platform chair seat for a thirty-minute period. Results showed that the exercise effect of the dual platform seat as it allows for self-alignment helps to meet the functional needs of the body during prolonged sitting.

**Oxford, H.W. ANTHROPOMETRIC DATA FOR EDUCATIONAL  
1969 CHAIRS.** *Ergonomics*, 12(2), 140-61.

In 1965, an extensive anthropometric survey was conducted to obtain eleven measurements of 12,000 pupils of all grades. Four hundred teachers were included. This paper is largely based on the data obtained from that survey. It was found that pupils differ in size to such an extent that a chair and table satisfactory for one pupil could be quite unsatisfactory for another in the same class. Three thousand pupils of all ages in New South Wales made it clear in 1968 that they did not wish to use chairs of equal height in any classroom. They preferred to sit on chairs equal to the length of the shod-lower-leg, or about 5mm to 8mm in excess of it.

**Randall, F.E. SEAT COMFORT.** *Mechanical Engineering*, 1056-58.  
1946

The basic problem in regard to supporting the body and posture of the body is the alleviation of localized pressures



inside or outside the body. Pressures inside the body arise from the forcing of joints into unnatural positions, which introduce compressions of joints and extensions of the ligaments and muscles normally involved in the joint motion. Pressures outside the body result from both the areas supporting the body and the unit pressures must be reduced to a minimum in order to achieve comfort. For all jointed portions of the body, efforts should be directed toward maintaining continuously the normal balance between opposing groups of muscles. Excessive discomfort due to external pressure is alleviated by increasing the area of support for the body to the maximum possible. The test methods established by Lay and Fisher are recommended for further use in the study of all problems of seating.

**Ridder, C.A. BASIC DESIGN MEASUREMENTS FOR SITTING.**  
1959 Fayetteville, Ark.: University of Arkansas, Bulletin 616.

An experimental chair was devised to collect data regarding the variations in size needed to support adults in common types of sitting postures. Subjects numbered 129 adults, 58 of whom were men and 71 women. The body measurements of the subjects were related to the measurements they selected for the experimental chair. Basic chair measurements were determined for common types of seating activities. One size was recommended for each of the three types of sitting positions as the best overall size for the majority of adults and for public or general use. A second size for each of the three types of sitting positions was also recommended for adults of greater than average stature and for individual use.

**Shackel, B., Chidsey, K.D., and Shipley, P. THE ASSESSMENT OF**  
1969 **CHAIR COMFORT.** *Ergonomics*, 12(2), 269-306.

The purpose of the two experimental programs described in this paper was the study of chair comfort evaluation methods in the context of selection for a potential user. In program I, three separate experiments were made, with the same chairs and three panels of 20 subjects, under conditions of long-term sitting, sitting at a desk and eating a meal. The results were: hardly any significant differences between male

and female subjects; significant decrease in comfort ratings with time; significant differences in comfort ratings between chairs; only small correlation between chair comfort preference order for different tasks, suggesting the need for different optimum designs, yet significant concordance between tasks to suggest that an acceptable compromise can be achieved in one design; significant correlation between rankings before trials and comfort test results, suggesting a possibly useful technique. In program II, experienced research workers in the ergonomics of chairs and sitting agreed to be the test subjects, since if these methods are valid, then positive results would be most likely to come from such experts. However, the results did not support the validity of assessment based on subjective opinions or B.S.I. recommendations; with the methods and time used in this study, it is clear that opinionative assessments cannot be given as valid predictors for the general population. Further analysis of some results yield significant correlations and differences between comfort test results and chairs ranked by size from B.S.I. recommended dimensions, suggesting the need for further work to improve recommendations and a useful technique for such studies. Problems of comfort criteria, chair selection, chair design, and test methods are discussed. The general conclusion is that seating comfort is still a very complex problem, and the only valid approach is the experimental method.

**Swearingen, J.J. DETERMINATION OF CENTERS OF GRAVITY  
1962 OF MAN.** Oklahoma City, Okla.: Civil Aeromedical Research  
Institute, August, 1962.

Data are presented concerning the location of the center of gravity of the adult male in various body positions and the ability to shift the c.g. voluntarily with various body motions. Maximum possible shifts of the c.g. from that of an erect standing posture were found to be 11½ inches toward the head, 10 inches toward the feet, 8 inches anteriorly, 4½ inches posteriorly and 4½ inches laterally.

**Swearingen, J.J., Wheelwright, C.D., Garner, J.D. AN ANALYSIS  
1962 OF SITTING AREAS AND PRESSURES OF MAN.** Civil

Aero Medical Research Institute, Federal Aviation Agency,  
Aeronautical Center, Oklahoma City, Oklahoma, 1-10.

Studies of sitting area on a plane rigid surface for a group of 104 male subjects were made. Area was found to vary with height and weight and to increase with age up to 40 years after which there is a steady decline. Sitting contact area was found to increase with experimentally applied force of magnitudes up to something less than body weight. Analysis of pressure distribution in the sitting area reveals that nearly half of the body weight is supported on 8 percent of the sitting area. This high pressure area is under or adjacent to the ischial tuberosities. Over one-third of the body weight on the sitting area is removed by the addition of a footrest, chair arms, and a slightly sloping seat back.

Wachsler, R.A. and Learner, D.B. AN ANALYSIS OF SOME  
1960 FACTORS INFLUENCING SEAT COMFORT. *Ergonomics*,  
3(4), 315-20.

This study presents a re-analysis by correlation and factor analysis of data on the relative comfort of six Air Force pilot and crew seats. On the basis of the results obtained, the following conclusions may be drawn: Seats are rated in the same relative order of comfort after only 5 minutes of sitting time has elapsed as after 4 or more hours of sitting on the seats. People tend to rate the overall comfort of a seat mainly on the basis of the comfort of their backs and buttocks. The comfort of the neck and shoulders plays a secondary role while thigh and leg comfort seems to have little relationship to judgments of the overall comfort of a seat. It was found that the following seven types of measurements were measures of the same quantity, "Overall Comfort" of a seat: Actual time a subject is willing to sit in a seat (up to a maximum of seven hours), ratings of overall comfort after 5 minutes of sitting, predictions of total time he would be willing to sit in the seat made after 5 minutes of sitting, time of onset of first signs of discomfort, ratings of overall comfort after 4 to 7 hours of sitting, comfort of the back, comfort of the buttocks.

Woodson, W.E. and Conover, D.W. WORK SEATING. In Human  
1966 Engineering Guide for Equipment Designers, Berkeley and  
Los Angeles: University of California Press, 141-52.

Design principles are presented as a planning guide for good work seating. Special recommendations are made for secretarial chairs, drafting chairs, operator chairs, executive chairs, aerospace seating, aircraft passenger seats, high-density seating, audience seating and general furniture seating.

Wotzka, G., Grandjean, E., Burandt, H., Kretzschmar, H., and  
1969 Leonhard, T. INVESTIGATIONS FOR THE  
DEVELOPMENT OF AN AUDITORIUM SEAT.  
*Ergonomics*, 12(2), 182-97.

The study was designed to enable the development of an auditorium seat which meets specific functions while avoiding, to the maximum extent, discomfort. Sitting behaviour was analyzed during lectures by the multi-moment process. Subsequently, an auditorium seat was improved in stages by virtue of the results of seating tests. The final results was a recommended new auditorium seat which caused a minimum of discomfort in both reclining and forward inclined postures.

## Chapter VII

### NOISE

This chapter is divided into three sections, of which physiological responses to noise, the most basic and most simply investigated, comprise section (a). The work of Jansen (1969) leads the recent efforts to connect noise and physiology, with the work by Welch and Welch on *Physiological Effects of Noise* (New York, Plenum, 1970) summarizing the field as of that date. An interesting and relatively unknown article (Oken, et al., 1966) suggests that human response to noise is indistinguishable from response to "simulated danger which induced anxiety." Upon reading the article this response to noise can be translated as equivalent to terror. Although the ethics of such research might today be called into question with respect to its effects on participants, it has proven informative.

Section (b) concerns effects of noise on human performance. The extensive work in the field demonstrates conclusively that it is quite difficult to affect adversely the performance of a task through a sensory channel unrelated to the task, if the subject remains motivated. Broadbent, a leader in the field, summarizes his recent thinking in *Decision and Stress* (New York, Academic Press, 1971). Glass and Singer, in *Urban Stress: Experiments on Noise and Social Stressors* (New York, Academic Press, 1972), discuss experiments in which the response to noise did not affect the task being performed.

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but did affect performance of subsequent tasks. Much of the work reads as modest extensions of the early work of Morgan (1916). Kirk and Hecht (1963) report that noise need not be entirely undesirable, since it improves performance when introduced under conditions that approach stimulus deprivation.

This section also includes attempts to scale human response to noise on the basis of subjective reports. Kryter has summarized this line of research, largely his own, and other areas in *The Effects of Noise on Man* (New York, Academic Press, 1970). Although the human auditory system and human interpretive abilities are highly complex, the exploration of this complexity has been neglected because of the immediate need to develop a single index of human response which would have immediate practical applicability for specification and regulation of noise. This pressing need has existed for more than two decades, in which research has been primarily a series of expensive crash efforts to refine the indices further and to replicate previous data. But this basic approach has not been adequate to the complexity of the problem. Definitive work under the assumptions of a multivariate response model has yet to be done. Many popular works decry noise for a variety of reasons. These and other serious works on loudness and noisiness have been omitted from this chapter, mostly for reasons of time available for completing the bibliography. One work, however, which sees through the problem and concludes that almost any index is as good as another, should be mentioned here. It is J.B. Ollerhead's *Subjective Evaluations of General Aviation Aircraft Noise* (Technical Report, April 1968, Federal Aviation Administration Report No. FAA NO-68-35, contract FA67WA 1731).

Section (c) deals with surveys of responses to noise. Borsky (1961) reports early surveys which show little relation between responses and noise, a conclusion which has been reached many times. Borsky's recent work (1969), however, approaches the problem from a behavioral viewpoint, and may represent a conceptual breakthrough, although as yet only pilot studies have been given in brief technical reports, with regular publication to follow. The Traffic Noise Index (Griffiths, 1968) represents some interesting work on street noise, perhaps more sophisticated in its way than the work on aircraft noise. The Traffic Noise Index (TNI) takes into account both the level of and variation in noise, giving far more weight to variation.

Robinson (1969) extended the concept of the index with his "Noise Pollution Level" index. The greatest problem in this area is that individuals are unable to give an adequate response to the question "How bad is it?" on an absolute scale, however accurate they may be collectively in giving relative responses (see chapter on multidimensional scaling). Also, for some reason, investigators of aircraft noise have tended to predict noise levels, using the very indices that are being tested. It is thus not always clear whether the human responses or the predictive indices of aircraft noise levels are at fault in instances of poor correlation.

## NOISE

### Section (a): Physiological Responses to Noise

- Abey-Wickrama, I., A'Brook, M.F., Gattoni, F.G. and Herridge, C.F.  
1969 MENTAL HOSPITAL ADMISSIONS AND AIRCRAFT NOISE. *The Lancet*, 2(7633), 1275-77.

A retrospective study covering two years of admissions to a psychiatric hospital shows that there is a significantly higher rate of admission, especially in certain diagnostic categories, from inside an area of maximum noise arising from Heathrow Airport than from outside this area.

- Abramovich-Poliakov, D.K., Kangelari, S.S. and Rudenko, V.F.  
1966 EFFECTS OF NOISE AND VIBRATION ON THE GENERAL MORBIDITY. *Gigiena Truda I Professional, NYE Zabolovania*, 6, 47-49.

- Ades, H.W., Graybiel, A., Morrill, S., Tolhurst, G. and Niven, J.  
1958 NON-AUDITORY EFFECTS OF HIGH INTENSITY SOUND STIMULATION ON DEAF HUMAN SUBJECTS. *Journal of Aviation Medicine (Aerospace Medicine)*, 29, 454-67.

- Ades, H.W., *et al.* THE BENOX REPORT: AN EXPLORATORY  
1953 STUDY OF THE BIOLOGICAL EFFECTS OF NOISE. Office of Naval Research, Project NR 144079.

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Ando, Y. and Hattori, H. EFFECTS OF INTENSE NOISE DURING  
1970 FETAL LIFE UPON POSTNATAL ADAPTABILITY  
(STATISTICAL STUDY OF THE REACTIONS OF BABIES  
TO AIRCRAFT NOISE). *Journal Acoustic Society of  
America*, 47(4), part 2, 1128.

Andreyeva-Galanina, Y.T., Alekseyev, S.V. and Suvorov, G.A.  
1965 EXPERIENCE IN CREATING A COMPLEX OF ACOUSTIC  
CONDITIONS FOR STUDY OF THE EFFECT OF  
INDUSTRIAL NOISES ON A HUMAN ORGANISM. Joint  
Publications Research Service, Washington, D.C.

Anonymous. THE HAZARD OF NOISE. *Modern Medicine*, 36,  
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Anonymous. FRACTIONAL SLEEP, NOCTURNAL SLEEP  
1966 DISTURBANCES PROVOKED BY NOISE:  
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PREVENTATIVE MEDICINE PROBLEM. *Neurological  
Review*, 115, (Paris), 592-95.

Antony, A., Ackerman, E. and Lloyd, J.A. NOISE STRESS IN  
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ENDOCRINE RESPONSE OF MICE, RATS, AND GUINEA  
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1430-37.

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1961 INDUSTRIAL NOISE STANDARDS. U.S. Joint Publications  
Research Service, No. 4371, Washington, D.C., 10-18.

Atherley, G.R.C., Gibbons, S.L. and Powell, J.A. MODERATE  
1970 ACOUSTIC STIMULI: THE INTERRELATION OF  
SUBJECTIVE IMPORTANCE AND CERTAIN  
PHYSIOLOGICAL CHANGES. *Ergonomics*, 13(5), 536.

A preliminary study was carried out to determine the interrelation between "moderate" acoustical stimulation and certain physiological changes. It has been shown that "subjective importance" of the noise was a material factor effecting changes in skin resistance. Further studies were made of the effect of whole-day exposure to aircraft noise, typewriter noise, and white noise. The noises of high subjective importance, the aircraft and the typewriter, both showed measureable physiological changes, whereas that of low subjective importance (white noise) showed no significant change compared with control levels. Estimations from four subjects showed a marked decrease in 24-hour urinary 17-ketosteroid and eosinophils, and an increase in total white cell count, lymphocytes and neutrophils. It is suggested that "moderate" noise does not appear to act as a "conventional" stressor and it is further postulated that it may result in a characteristic syndrome which is comparable with a mild form of anxiety-depression.

Barutkina, T.S., Zarubayol, T.T., Mityushov, M.I., Panov, A.N. and  
1966 Rakitskaya, V.V. CHARACTERISTICS OF THE ACTIVITY  
OF THE ADRENAL CORTEX AND THE THYROID  
GLAND AND HIGHER NERVOUS ACTIVITY UNDER  
THE CONDITIONS OF THE PROLONGED ACTION OF  
SOUND. U. S. Joint Publications Research Service,  
N67-11437, Washington, D.C.

Bickford, R.G., Cody, D.T.R. and Jacobson, J.L. NATURE OF  
1964 AVERAGED EVOKED POTENTIALS TO SOUND AND  
OTHER STIMULI IN MAN. *Annals New York Academy of  
Science*, 112, 204-23.

A human "sonometer" response system has been described in which click stimuli produce widespread activation of the muscular system with latencies from 6 msec. (inoin, cervical) to 50 msec. (leg). These responses can be detected throughout the cranial musculature and are believed to be the basis of the so-called cortical responses to auditory stimulation. Studies using patients with various lesions of the audio-vestibular system have indicated that the receptors in

the "sonomotor" response are vestibular rather than cochlear. Hence, the test cannot be used as a valid measure of hearing function. A varying degree of myogenic contamination can be shown to accompany the average responses to other sensory inputs (light, somaesthetic) and suggest the need for caution in the interpretation of average responses derived from the human scalp.

Black, R.W. HEART RATE RESPONSE TO AUDITORY  
1964 STIMULATION OF VARYING DURATION. *Psychonomic Science*, 1, 171-72.

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Butler, R., Spreng, M. and Keidel, W. STIMULUS REPETITION  
1969 RATE FACTORS WHICH INFLUENCE THE AUDITORY EVOKED POTENTIAL IN MAN. *Psychophysiology*, 5(6), 655-72.

Catlin, F.I. NOISE AND EMOTIONAL STRESS. *Chronic Dis.*, 18,  
1965 509-19.

Chapek, A.V., Mirzoyev, B.M. and Somonov, V.N. THE  
1966 INFLUENCE OF IMPULSE NOISE CREATED BY MODERN AIRPLANES ON THE HUMAN ORGANISM. U.S. Joint Publications Research Service, N67-11668, Washington, D.C.

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1959 NOXIOUSNESS OF NOISE. LAWS OF UNBALANCE DUE  
TO THE ACTION OF SOUND ON NERVE CENTERS.  
*Presse Medicale*, 67, 2253-54.

Chisman, J.A. and Simon, J.R. PROTECTION AGAINST  
1961 IMPULSE-TYPE INDUSTRIAL NOISE BY UTILIZING THE  
ACOUSTIC REFLEX. *Journal Appl. Psychol.*, 45(6), 402-7.

It has been known for some time that certain tones above approximately 70 dB. sound pressure level (SPL) elicit a consensual reflex contraction of the two intra-aural muscles, the tensor tympani and the stapedius. This response, known as the AR, reduces the transmission of sounds through the middle ear and acts to minimize possible cochlear damage from overstimulation by loud sounds. Results are interpreted to suggest that eliciting the acoustic reflex prior to an impact may be an effective means of protecting the ear against industrial impulse noises. The advantages of AR protection over protection provided by earplugs are discussed.

Cohen, A. NOISE EFFECTS ON HEALTH, PRODUCTIVITY AND  
1968 WELL-BEING. *Transactions of the New York Academy of  
Sciences*, 30, 910-18.

Cole, J.N., Guild, E., Mohr, G.C. and von Gierke, H.E. EFFECTS  
1965 OF LOW FREQUENCY AND INFRASONIC SOUND ON  
MAN. *Aerospace Medicine*, 36, 817-24.

Connors, K. and Greenfield, D. HABITUATION OF MOTOR  
1966 STARTLE IN ANXIOUS AND RESTLESS CHILDREN.  
*Journal Child Psychology and Psychiatry*, 7, 125.

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1964 ENOLOGICAL ASPECTS. *Journal Acoustical Society of  
America*, 36(11), 2175-83.

Davies, D.R. PHYSIOLOGICAL AND PSYCHOLOGICAL EFFECTS  
1968 OF EXPOSURE TO HIGH INTENSITY NOISE. *Applied  
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Davis, H. (Ed.) AUDITORY AND NON-AUDITORY EFFECTS OF  
1958 HIGH INTENSITY NOISE. Project Anaheim Final Report,  
Joint Project 13-01-99 subtask 1, report 7, Central Institute  
for the Deaf and Naval School of Aviation Medicine,  
Pensacola.

Davis, H., Bowers, C. and Hirsh, S.K. RELATIONS OF THE  
1968 HUMAN VERTEX POTENTIAL TO ACOUSTIC  
INPUT-MASKING AND LOUDNESS. *Journal Acoustical  
Society of America*, 43(3), 431-38.

The rate of increase of amplitude of V (vertex) potentials with the SPL on tone bursts is very slow. In one experiment, the exponent of the power law was 0.15 at 250 Hz, 0.11 at 1000 Hz, and only 0.08 at 4000 Hz. Individual differences across subjects seemed more important than the interval between stimuli (1 sec vs. 3.2 sec), and variability across trials often obscured the relation to intensity. In the presence of appropriate bands of masking noise, the input output curves rise abruptly from the masked threshold to approach the unmasked amplitude at a level about 30 dB. above the corresponding masked threshold. The effect resembles recruitment of loudness. Tone pips and tone bursts of different frequency that were judged equally loud evoked slow V potentials of approximately equal amplitude. In some subjects, however, bursts of white noise evoked significantly larger responses than equally loud tone bursts or pips. In spite of the partial similarities between them, the amplitude of the V potential and the sensation of loudness are related differently to the parameters of the acoustic stimulus.

Davis, R.C. MOTOR EFFECTS OF STRONG AUDITORY  
1948 STIMULI. *Journal of Experimental Psychology*, 38, 257-75.

To study possible motor responses to sensory stimuli two experiments were conducted in which there was a recording of muscular action potentials in both forearms under loud sound stimulation. The subjects were instructed to do nothing in response to the stimuli. An increment in action potential over the immediate pre-stimulus level was considered to be

a response. The first experiment was designed to study the nature of the response and the effects of stimulus intensity and repetition on it. The second was to investigate the effects of pre-stimulus tension pattern upon the response, and used states of induced tension in the left and right arms, in addition to a "normal" condition. The following results were obtained: (1) Stimuli of the sort used here may be said to produce two responses, *a* and *b*, since two parts of the overall response curve have different functional relations. (2) The *a* response has a latency of about 0.1 sec., reaches its peak during the next 0.1 sec. after stimulus onset and in a large part disappears during the next 0.5 sec. (3) The *a* response shows marked and rapid adaptation, practically disappearing with a half dozen stimulations two minutes apart. (4) The *a* response varies with stimulus intensity, and probably would not appear with a stimulus of much less than the 90-100 dB. at 500 cycles used here. (5) The *b* response, the latency of which cannot be determined exactly from these data, reaches its maximum generally about one second after the onset of the stimulus, and on the average stays at that level for about another second thereupon declining. (6) The *b* response isn't affected by stimulus intensity or repetition within the limit of the experiment. (7) Both *a* and *b* responses are closely related to the state of tension existing just before the delivery of the stimulus. The size of both reactions is a function of this tension level, and the geographical patterns are dependent upon it. The response pattern is not, however, in simple conformity to the pre-existing tension pattern: response excitation in one location is facilitated by ipsilateral tension and slightly inhibited by contralateral tension. These responses are probably related to some previously studied by other methods, but a complete theory must await more information.

Davis, R.C. and VanLiere, D.W. ADAPTATION OF THE  
1949 MUSCULAR TENSION RESPONSE. *Journal Experimental Psychology*, 39, 114-17.

DeLeon, G. CONDITIONING THE HUMAN HEART RATE WITH  
1964 NOISE AS THE UNCONDITIONED STIMULUS. *Journal  
Experimental Psychology*, 68(5), 518-20.

An attempt was made to replicate, with light and noise, the heart-rate conditioning findings obtained with tone and shock by Notterman, Schoenfield, and Bersh (1952). An EEG was adapted for a cardiograph. With eight human subjects a conditioning procedure was implemented in which a one second light (CS) preceded a six second noise (UCS) by an interval of six seconds. The results showed that after several such pairings the light came to exercise a depressant effect on the heart rate. Moreover, the characteristics of the CR in extinction, spontaneous recovery, reconditioning, and a second extinction paralleled those of the CR obtained with tone and shock.

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1966 HEARING LOSS. *New England Journal of Medicine*, 275,  
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1948 AND MECHANICAL VIBRATIONS OF A TURBOJET  
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MUSCLE REFLEX ACTIVITY. *Aerospace Medicine*, 34,  
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**Freeman, G.L.** CHANGES IN TENSION-PATTERN AND TOTAL ENERGY EXPENDITURE DURING ADAPTATION TO DISTRACTING STIMULI. *Amer. J. Psychol.*, 52, 354-60.

The results of this study suggest that the initial effect of distracting stimuli is to temporarily unbalance a bodily economy in which, for habitual acts at least, supporting processes operate at an optimal level. The subject's efforts to compensate for the distraction is expressed by a rise in total energy expended and by a shift in the pattern of supporting processes. Neuromuscular activity spreads to bodily parts remote from the task at hand; the original focus of the pattern tends to be lost. Under repetition of the stimulation, however, this "irradiation" effect becomes less prominent and the economical concentration of supporting processes in limited areas begins to reappear. Such redevelopment of a focalized response pattern may involve slightly greater supporting tensions, but these changes do not seem to have much effect on the economy of total energy expenditure.

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**Geber, W.F.** DEVELOPMENTAL EFFECTS OF CHRONIC MATERNAL AUDIOVISUAL STRESS ON THE RAT FETUS. *J. Embryol. Exp. Morphol.*, 16, 1.

**Geber, W.F. and Anderson, W.T.** EFFECTS OF CHRONIC INTERMITTENT NOISE STRESS IN RAT AND RABBIT. *Comp. Biochem. Physiol.*, 21, 273.

**Geber, W.F., Anderson, T.A., Van Dyne, B. and Vermillion, S.D.** PHYSIOLOGIC RESPONSES OF THE ALBINO RAT TO CHRONIC NOISE STRESS. *Arch. Envir. Health*, 12, 751-54.

**Goldsmith, J.R. and Jonsson, E.** EFFECTS OF NOISE ON HEALTH IN THE RESIDENTIAL AND URBAN ENVIRONMENT. American Public Health Association.



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In the light of present neurophysiological knowledge we may consider fatigue as a state of the central nervous system controlled by the antagonistic activity of the inhibitory and activating system of the brain stem. The regulating systems in turn are susceptible to reaction to stimuli from the surrounding world, to stimuli from the conscious part of the brain, and to humoral factors originating within the organism and having obviously the task of regulating recovery and wakefulness. The state of fatigue is accompanied by a decrease in motivation to work, a decrease in physical and mental performances, and by the occurrence of subjective feelings of fatigue. The latter induce animals and human beings to a behavior ensuring recovery.

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and Hearing Research*, 13(1), 130-46.

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47-53.

Jansen, G. EFFECTS OF NOISE ON PHYSIOLOGICAL STATE.  
1969 Conference on Noise as a Public Health Hazard, American  
Speech and Hearing Association, 89-98.

Meaningless noise can elicit another kind of response, vegetative reaction. In our study a meaningless noise (white noise, 90 dB. SPL) to which tested persons were accustomed, effected changes in peripheral vegetative functions, such as the peripheral circulatory system and the pupillary function. The dilation of the pupil occurred constantly during exposure to noise stimuli. By using a plethysmographic method (as photoelectrical, thermoelectrical, and fluvographical recordings), we found that blood volume in the skin was reduced, because of a vasoconstrictive effect. Calculating the stroke volume of the heart from sphygmographic and/or ballistographic recordings, we found a decrease of volume synchronized with the noise induced vasoconstriction. Increase of diastolic blood pressure was often noted but disappeared sometimes after repeated testing over a period of several months.

Jansen, G. EFFECTS OF NOISE ON HEALTH. *German Medical Monthly*, 13, 446-48.

Experimental work and field studies concerned with psychosomatic effects of noise have demonstrated extra-aural functional changes occurring independently of occupational deafness or any conscious disturbance. The result is that doctors concerned with prophylaxis must assume—until the contrary is proved—that noise can be harmful, especially to those whose vulnerability has been increased for any reason. The results of research clearly justify medical demands for effective noise reduction so that health shall not be endangered. It is not uncommonly maintained by acoustic engineers that people can get used to noise and so noise reduction is not necessary to the extent demanded. The research of the last few years has shown that the autonomic nervous system, at least, does not become accommodated in this way, even though psychological adjustment may be excellent. This research has provided evidence which shows that medical demands are justified.

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Noise levels in a ten-bed recovery room, 30 x 15 x 10 feet in dimension, were measured at half-hour intervals on five random work days using a portable battery operated sound level meter. The median noise level was found to be within 50-60 decibels. Periods of heightened activity, presence of large numbers of staff personnel, overcrowding of patients, and certain sound effects such as crying, laughing, groaning, snoring and the ringing of the telephone produced noise levels between 60-70 decibels, with spikes of sound reaching 80+ decibels. Lowest sound levels fell between 40-50 decibels. It was hypothesized that patients' subjective sensation of pain in the immediate postoperative period would be increased at times when noise levels were high; that noise in the external environment represents an increased irritant to the patient who is already experiencing postoperative pain; and that if this were true more pain medication would be given to patients per capita at times of high noise levels than at times of low noise levels. The result of this five day study supports the hypothesis. In addition, the result indicates that semi-conscious recovery room patients do interpret the quality, character, and meaning of certain noises, and that this plays an important part in their reaction to noise.

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This paper has been concerned with the issue of whether there is specific patterning of the physiological responses to different types of stimuli. In particular we have focused on Lacey's hypothesis that there are two different patterns associated with stimuli which lead to "intake" or "rejection" of the environment. We have presented the data on the effects, in thirty-three subjects, of exposure to a one-minute white noise stimulus followed later by a five-minute situation of simulated danger which induced overt anxiety. The noise produced a fall in diastolic blood pressure and rises in all other physiological variables. The anxiety stress was associated with rises in all the physiological measures to an extent which exceeded the response to the white noise. It was suggested that the two responses differ only in magnitude, and it was explained that even the fall in diastolic pressure below baseline is consistent with such an interpretation. Specificity of patterning, therefore, is not confirmed by these data. Both stimuli can be viewed as producing the same stress response, the anxiety situation being only more potent than the noise stimulus.

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*Electroencephalograph Clin. Neurophysiol.*, 23, 291.

Continuous EEG monitoring of sleep easily reveals variations in depth following sensory stimuli. Together with the appearance of K complexes this objectivity demonstrates a more or less frequent impairment of sleep of which the individual concerned is usually unaware. Noise associated with modern civilization (automobiles, trucks, elevated and underground railways, jets, and even natural sounds) frequently disturb the rest of sleepers—the trophotropic phase of restitution—and in this way help facilitate neurovegetative imbalance and lability. City builders and traffic engineers should take into consideration the need and right of every human being to rest, a factor indispensable to health.

Roessler, R, Collins, F. and Burch, N. HEART RATE RESPONSE  
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The effects of the 80 decibel stimulation on stomach movements are marked. There is a decrease of 37 percent in the number of contractions per minute caused by this noise. In addition, in some subjects there is a complete change in type of contraction, and the size of the major contractions is considerably decreased. The stomach relaxes more slowly than during relative quiet. In short, there is a general lessening of stomach activity corresponding to those observed by Cannon in the cat frightened by the dog. The aftereffects in the following quiet period vary somewhat with the individual; some subjects show an overcompensatory quickening of rhythm, accompanied by more vigorous contractions. Others simply return slowly to normal. Sounds of 60 decibels do not have as marked an effect on stomach movements. There are, however, about 10 percent fewer contractions per minute, and a slightly altered type of contraction wave. The aftereffects were similar to those observed under the 80 decibel stimulation, but in a lesser degree. In conclusion it may be said that the experiment indicates a rather profound effect on involuntary muscular activities of the stomach with noises of 60 decibels or above. These effects are at least similar to those produced by what is generally called fear, if, indeed, they are not essentially a fear reaction.

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The noise factor affects the nervous system of children. On chronic action of noise at an intensity of 65-75 dB., the latent period of the conditioned reflexes to noise and auditory stimuli lengthens considerably. The experimental findings obtained show that the lot intended for the building of a preschool institution must be chosen with due regard for the determined values of noise on the site of the future building. Preschool institutions must be situated in such a way that noise intensity on the children's playground should not exceed 40 dB.

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Tsyar, A. EFFECTS OF COMBINED NOISE AND VIBRATION ON  
1966 THE CARDIOVASCULAR SYSTEM OF WORKING ADOLESCENTS. *Hygiene and Sanitation*, 31, 193-99.

The reaction of the cardiovascular system in adolescents to the action of noise in combination with vibration and to that of noise alone proved to be quite different. After a comparatively short time of work with vibration instruments, the adolescents showed a reduced recovery capacity in the cardiovascular system, in unaltered indices of pulse, and in arterial pressure and also showed a rise of the vascular tone. School pupils, undergoing industrial training and exposed to the action of noise and vibration, revealed a certain tendency to development of angiospasm of peripheral vessels due to the lengthening of time of appearance of reactive hyperemia. This confirms the high sensitivity and reactivity of the adolescent's body to the investigated factor.

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## NOISE

### Section (b): Effect of Noise on Human Performance

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Atherley, G.R.C., Gibbons, S.L. and Powell, J.A. MODERATE  
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*Journal of Engineering Psychology*, 4, 9-21.

Baker, C.H. TOWARDS A THEORY OF VIGILANCE. *Canad. J.*  
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Bieri, J. and Meyers, B. DIFFERENTIAL EFFECTS OF TWO  
1968 TYPES OF AVERSIVE AROUSAL ON  
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The effects of two types of aversive arousal, white noise and electric shock, upon discriminability was investigated in two studies using information analysis. Results indicated that while discriminability was affected in both studies as a function of arousal, there was a differential effect in the unreliability component of responses. White noise increased the unreliability of responding while shock tended to decrease the unreliability. These differences are discussed in terms of drive and attention properties of the two forms of arousal.

**Boggs, D.H. and Simon, J.R. DIFFERENTIAL EFFECT OF NOISE  
1960 ON TASKS OF VARYING COMPLEXITY. *Journal of Applied Psychology*, 52, 148-53.**

This method of simultaneous tasks was used to test the hypothesis that the deleterious effect of noise on performance varies as a function of task complexity. Forty-eight subjects simultaneously performed on 1 of 2 complexity levels of a 4-choice RT task and a secondary auditory monitoring task. All subjects performed both in quiet and noise. Performance indices were RT and secondary-task errors. Noise produced a significantly greater increase in secondary-task errors when the secondary task was paired with the complex primary task than when it was paired with the simple primary task. Secondary-task performance provided a more sensitive measure of both task complexity and the effect of noise than did the RT measure.

**Broadbent, D.E. ON THE DANGERS OF OVER-AROUSAL. IAA  
1965 Preprint 1, Medical Research Council, Cambridge, England.**

**Broadbent, D.E. DIFFERENCES AND INTERACTIONS BETWEEN  
1963 STRESSES. *Quart. J. Exp. Psychol.*, 15, 205-11.**

This paper reviews a number of experiments in which different stresses have been applied to comparable subjects performing similar tasks. It is argued that, since the effects of the stresses are different, it is not legitimate to think of a single mechanism mediating reaction to stress. Experiments

on the simultaneous application of two stresses show that the effects of heat appear to be independent of those of noise and sleeplessness, while the latter two conditions partially cancel each other. It is therefore argued that noise and sleeplessness affect the same mechanism in opposite directions, while heat affects some other mechanism. Tentatively, noise is regarded as over-arousing and lack of sleep as under-arousing.

**Broadbent, D.E. EFFECT OF NOISE ON AN "INTELLECTUAL" 1958a TASK.** *J. Acoust. Soc. Amer.*, 30(9), 824-28.

Three groups of Naval Ratings worked for two sessions each at a subtraction task involving considerable immediate memory load. One group had both sessions in 100 dB noise and the second in quiet, and the third group had noise and quiet in the reverse order. In the first session the noise group slowed down at solving the subtractions as time went on, relative to the groups working in quiet. A similar difference appeared in the second session, but, in addition, there was an aftereffect of noise such that the subjects who had had noise previously slowed down relative to those who had not. Slowing down of performance with time was in all groups most marked in extroverts. These results suggest firstly that intellectual work as well as simple sensory tasks must be regarded as endangered by noise. Secondly, there may be harmful aftereffects from noise, but it is not clear whether these will appear in any situation or only in one similar to that in which the noise was experienced.

**Broadbent, D.E. PERCEPTION AND COMMUNICATION.** Pergamon 1958b Press, New York, New York.

**Broadbent, D.E. EFFECTS OF NOISES OF HIGH AND LOW 1957a FREQUENCY ON BEHAVIOR.** *Ergonomics*, 1, 21-9.

Three groups of subjects worked for two sessions in noise at a five-choice serial reaction task. During one session the noise was restricted to frequencies above 2000 c.p.s., and during the other to frequencies below. The high frequency

noise gave more errors in performance, although the difference was significant only at the highest intensity of 100 dB. When reaction times were measured to the same noises, the first reaction of a series with the same type of stimulus was slower when the stimulus was low intensity and low frequency. With high frequency or high intensity stimuli this was not so. It thus appears that sounds more likely to interfere with work also produce a faster reaction when themselves acting as signals, confirming a view already advanced about noise effects: that the effect is due to competition between various stimuli to control response.

**Broadbent, D.E. NOISE AND BEHAVIOR.** *Proceedings of the Royal Society of Medicine*, 50, 225-8.

There is a process like blinking but located between the sense-organs and the main body of the nervous system, and producing interruptions of the flow of incoming information which last perhaps a second rather than the small fraction of a second taken by true blinks. These internal blinks are supposed to be increased in frequency by noise, and they would produce just the effects on behavior which are in fact observed. There would be no effect on short tasks nor on those which contain periods in which the worker knows that nothing will happen. But there would be a delay in noticing unexpected events, and there would be momentary errors in responding to a truly continuous stream of stimuli.

**Broadbent, D.E. LISTENING BETWEEN AND DURING PRACTICED AUDITORY DISTRACTIONS.** *Brit. J. Psychol.*, 47, 51-60.

**Broadbent, D.E. SOME EFFECTS OF NOISE ON VISUAL PERFORMANCE.** *Quarterly Journal of Experimental Psych.*, 6, 1-5.

A group of ten subjects showed impaired performance, when watch-keeping on a display made up of steam-pressure gauges, in 100 dB noise as compared with 70 dB. On the easier task of watch-keeping on a display made up of small



lights, another group of twenty subjects showed no overall effect of noise. Individual subjects who showed a practice effect on the latter task comparable to that shown by all subjects on the former one, however, also showed a similar effect of noise. In addition, performance on the light-watching became relatively less efficient in noise with continued exposure; and although parts of the task were still adequately carried out, others were not. The fact that noise effects are thus functions of individual differences, of visibility of signal, and of length of performance in noise, allows us to explain the negative findings of many previous workers.

Broadbent, D.E. NOISE, PACED PERFORMANCE AND  
1953 VIGILANCE TASKS. *British Journal of Psych.*, 44, 295-303.

Broadbent, D.E. FAILURES OF ATTENTION IN SELECTIVE  
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Broadbent, D.E. and Burns, W. EFFECTS OF NOISE ON HEARING  
1965 AND PERFORMANCE. Ministr. Def. Med. Res. Coun.,  
report 65-1057, *Amer. Sp. Hear. Assoc., Report 4*, 87.

Broadbent, D.E. and Gregory, M. EFFECTS OF NOISE AND OF  
1965 SIGNAL RATE UPON VIGILANCE ANALYZED BY  
MEANS OF DECISION THEORY. *Human Factors*, 7,  
155-62.

A vigilance task was performed in which regular flashes of light were monitored for an occasional flash of greater brightness. Following every flash a decision of signal present, signal absent, or doubtful, had to be recorded. Two separate groups received high and low signal rates with a variety of the task in which the flashes occurred only on one lamp; another group received a high signal rate divided between three simultaneously flashing lights. An analysis in terms of decision theory showed that detrimental changes during the watch period were entirely attributable to movement of the subject's criterion for reporting a signal: His sensitivity to the signals if anything improved during the work period. In

addition, criterion changes in the presence of intense noise occurred at high signal frequencies, even when only one source of information was involved, thus showing that division of attention between different sources is not essential for harmful effects of noise. In addition, criteria under quiet conditions were different at different signal rates.

**Broadbent, D.E. and Gregory, M. VIGILANCE CONSIDERED AS  
1963 A STATISTICAL DECISION. *Brit. J. Psychol.*, 54, 309-23.**

A number of experiments are described in which untrained subjects kept watch during long periods for inconspicuous signals. When they reported such a signal, they had to indicate their degree of confidence that the report was correct. By analyzing the accuracy of reports in each category of confidence, it can be shown that they are quite inconsistent with the concept that stimuli are either definitely perceived or definitely fail to be detected, with no intermediate category. The results are more consistent with a model of perception as the outcome of statistical decision made with more or less caution upon the evidence contaminated by randomness. Analyzing the empirical data according to this model, neither the duration of a watch nor the presence of loud noise during visual experiments affect the degree of randomness in the evidence used for decision. Both factors do, however, affect the degree of caution with which the decision is made, and this may explain the failures of perception previously found in experiments upon prolonged watch and upon noise. Changes during the watch appear primarily, however, when the decision is made cautiously (with few false detections) while the changes with noise appear rather as a lessening of the difference between cautious and risky behavior. This divergence between the effects of noise and of prolonged work may explain the fact that experimental conditions which reveal effects of noise have not always in the past been those which are sensitive to effects of prolonged work.

Broadbent, D.E. and Heron, A. EFFECTS OF SUBSIDIARY TASK  
1962 ON PERFORMANCE INVOLVING IMMEDIATE MEMORY  
BY YOUNGER AND OLDER MEN. *Brit. J. Psychol.*, 53,  
189-98.

Broadbent, D.E. and Little, E.A.J. THE EFFECTS OF NOISE  
1960 REDUCTION IN A WORK SITUATION. *Occupational  
Psychology*, 34, 133-40.

Brown, I.D. A COMPARISON OF TWO SUBSIDIARY TASKS  
1965 USED TO MEASURE FATIGUE IN CAR DRIVERS.  
*Ergonomics*, 8, 467-73.

Car driving has been studied by combining it with a subsidiary task, performance on which is negatively correlated with the perceptual load imposed by changing conditions of traffic. The present experiment compares a subsidiary task which required almost continuous attention to an auditory display, and which involved memory spans of only 3 sec. with an alternative task which did not require continuous attention, but which involved memory spans of up to 55 sec. The former was found to have some advantages. This comparison was combined with a study of men engaged in 8-hour spells of car driving. Some explanations are offered for the finding that performance on the subsidiary tasks was better at the end of the workspell than at the beginning.

Brown, I.D. and Poulton, E.C. MEASURING THE SPARE  
1961 "MENTAL CAPACITY" OF CAR DRIVERS BY A  
SUBSIDIARY TASK. *Ergonomics*, 4, 35-40.

It is impossible to determine the degree to which a driver is absorbed in his driving by measuring his overt responses directly. However, relatively small changes in his spare "mental capacity" can be detected by scoring his performance on a subsidiary task which has no adverse effect upon driving. This technique is sufficiently sensitive to reveal the higher level of concentration required in a shopping area as compared with that required in a residential area.

Brown, R.L., Galloway, W.D. and Gildersleeve, K.R. EFFECTS OF  
1965 INTENSE NOISE ON PROCESSING OF CUTANEOUS  
INFORMATION OF VARYING COMPLEXITY. *Percep.  
Mot. Skills*, 20, 749-54.

Buckner, D.N. and Harabedian, A. HUMAN INFORMATION AS A  
1965 FUNCTION OF SELECTED VISUAL AND AUDITORY  
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Report 2, Los Angeles, California.

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1960 AND MISAPPLIED. *J. Acoust. Soc. Amer.*, 32(12), 1568-74.

Carpenter, A. EFFECT OF NOISE ON PERFORMANCE AND  
1961 PRODUCTIVITY. Control of Noise, National Physical  
Laboratory, England, 297-310.

Cohen, A. NOISE EFFECTS OF HEALTH, PRODUCTIVITY AND  
1968 WELL-BEING. *Tran. N. Y. Acad. Sci., Ser. 2*, 30(7).

Noise can adversely affect man in various ways. For example, prolonged exposures to intense noise may damage sensory cells and other body tissues as seen in cases of noise-induced hearing loss. Noise may mask speech reception needed to accomplish a task, disrupt one's ability to attend to a job, or otherwise complicate work performance. Noise may disturb rest, relaxation and sleep. In short, noise may affect the health, productivity, and well-being of people. This presentation discusses the current status of knowledge regarding such noise effects in the context of examining noise problems in industry, in the community, and in the home.

Cohen, A. EFFECTS OF NOISE ON PERFORMANCE. Proceedings  
1967 of the International Congress on Occupational Health A IV,  
157-60.

Cohen, A., Hummel, W.F., Turner, J. and Dukes-Duboes, F.N.  
1966 EFFECTS OF NOISE ON TASK PERFORMANCE.  
U.S.P.H.S., Div. of Occup. Health.

Colquhoun, W.P. THE EFFECT OF "UNWANTED" SIGNALS ON  
1961 PERFORMANCE IN A VIGILANCE TASK. *Ergonomics*, 4,  
41-51.

Corcoran, D.W.J. NOISE AND LOSS OF SLEEP. *Quart. J. Exp.*  
1962 *Psychol.*, 14, 178-82.

Two experiments are reported in which human performance was compared under continuous 90 dB. white noise, after loss of sleep, under a combination of the two and under appropriate control conditions. The results suggest that noise is effective in reducing the deterioration in performance characteristic of loss of sleep. The relevance of the result to the arousal theory of loss of sleep is discussed.

Davies, D.R. and Hockey, G.R.J. THE EFFECTS OF NOISE AND  
1966 DOUBLING THE SIGNAL FREQUENCY ON INDIVIDUAL  
DIFFERENCES IN VISUAL VIGILANCE PERFORMANCE.  
*Brit. J. Psychol.*, 57, 381-9.

Four groups of 6 extroverts and 4 groups of 6 introverts, selected by the Maudsley Personality Inventory, performed a 32 min. visual cancellation task under one of two conditions of signal frequency, high and low, and in either noise (95 dB) or quiet (70 dB). In quiet, at both levels of signal frequency, extroverts showed a steady decline in the number of signals detected correctly, but introverts did not. Neither group showed a decrement under noise conditions. Noise, compared with quiet, significantly increased the number of correct detections made by extroverts under low signal frequency conditions, but a similar increase under high signal frequency conditions was not significant. The addition of noise had no significant effect on the number of correct detections made by introverts. Doubling the signal frequency had no significant effect on the performance of introverts or extroverts in either noise or quiet. Introverts made significantly more errors of commission in quiet than in noise, while extroverts made significantly more in noise than in quiet. Possible reasons for the findings are discussed.

Dean, R.D. and McGlothlen, C.L. EFFECTS OF COMBINED HEAT  
1965 AND NOISE ON HUMAN PERFORMANCE, PHYSIOLOGY  
AND SUBJECTIVE ESTIMATES OF COMFORT AND  
PERFORMANCE. Inst. of Environmental Sciences (11th)  
Annual Technical Meeting Proceedings, 55-64.

Ten pilots were tested under 20-minute exposure periods to ten combinations of heat and noise. The subjects performed simultaneously two monitoring tasks and one tracking task. Data were also obtained on six physiological measures and two subjective measures. The data indicated that temperatures as high as 110°F (at 50% relative humidity and 150-feet-per-minute air velocity) and white noise as high as 110 dB did not degrade performance or thermal equilibrium. Heat was found to increase heart rate, axillary temperature and thigh temperature, but had no effect on rectal temperature. Noise was found to increase heart rate and respiratory rate. The interaction between noise and heat suggested that noise lowered thigh temperature at ambient temperatures in the vicinity of 100°F. The subjective data indicated that 80°F was the most comfortable temperature at the levels of humidity and air velocity used. The subjects were unable to accurately estimate the effects of heat on their performance, although they were able to estimate the effects of noise.

DeBarbenza, C.M., Bryan, M.E. and Tempest, W. INDIVIDUAL  
1970 LOUDNESS FUNCTIONS. *J. Sound Vibration*, 11(4),  
399-410.

Dornic, S. EFFECT OF NOISE ON VISUAL AND AUDITORY  
1967 MEMORY SPAN. *Scand. J. Psychol.*, 8, 155-60.

Messages of visual and aural stimuli (digits) were presented together with a specific noise consisting of different auditory and visual stimuli. The auditory memory span, measured by the amount of digits recalled immediately after presentation, was not at all affected by the interfering visual noise, whereas, the visual memory span was found to be significantly reduced by the acoustic noise. The results are

interpreted as giving support to the hypothesis on the acoustic nature of information storage in immediate memory. Possible difference in the properties of the visual and auditory peripheral filter are discussed.

Eldredge, D. PROACTIVE INHIBITION, RECENCY AND  
1967 LIMITED-CHANNEL CAPACITY UNDER ACOUSTIC  
STRESS. *Percep. & Motor Skills*, 25, 85-91.

This study investigated the effects of an increase in the level of acoustic stress (signal-to-noise ratio) on the retrieval of message sets of 2, 3, or 4 unrelated words presented successively. The results indicated that noise degradation did affect the efficiency with which subjects retrieved sentences of successively presented items. It was noticed that the retention of the initial item of a message set caused a marked decrement in the retention and retrieval of subsequent items of the message set and that the effect increased as a function of the number of words presented. The effects were attributed to proactive inhibition, recency, and limited-channel capacity.

Felton, J.S. and Spencer, C. MORALE OF WORKERS EXPOSED  
1961a TO HIGH LEVELS OF NOISE. *Amer. Indus. Hyg. Assn. J.*, 22, 137-47.

Felton, J.S. and Spencer, C. MORALE OF WORKERS EXPOSED  
1961b TO HIGH LEVELS OF OCCUPATIONAL NOISE. University  
of Oklahoma School of Medicine.

Finkleman, J.M. and Glass, D.C. REAPPRAISAL OF THE  
1970 RELATIONSHIP BETWEEN NOISE AND HUMAN  
PERFORMANCE BY A MEANS OF A SUBSIDIARY TASK  
MEASURE. *J. Appl. Psychol.*, 54, 211-213.

Previous research has generally shown that broad-band noise has only minimal effects on task performance. However, this relative absence of effect may be attributable to the way in which earlier investigators measured performance decrements. The present study was based on the notion

that where demands imposed by the task and concurrent environmental stress are within the operator's total information handling capacity, the task can be performed substantially without errors. For performance degradation to occur, the operator's channel capacity must be exceeded. It was assumed that unpredictable noise in combination with multiple task performance would result in such an overload, whereas the introduction of predictable noise would not have such an effect. A subsidiary task method consisting of the delayed recall of randomly presented digits was used to measure overload. As expected, the use of unpredictable, as opposed to predictable noise resulted in performance degradation on the subsidiary task. Performance on the primary task was unaffected by either type of noise. These results were interpreted as reflecting a reduction in spare mental capacity as a function of the aversiveness of the noise stressor.

Fornwalt, N.E. INVESTIGATION INTO THE EFFECT OF  
1965 INTERMITTENT NOISE OF CONSTANT PERIODICITY  
VS. RANDOM PERIODICITY ON THE PERFORMANCE  
OF AN INDUSTRIAL TASK. Master's Thesis, Department  
Industrial Engineering, Texas Techno. College.

Frith, C.D. THE INTERACTION OF NOISE AND PERSONALITY  
1967 WITH CRITICAL FLICKER FUSION PERFORMANCE.  
*Brit. J. Psychol.*, 58, 127-31.

Noise for the noisy condition was produced by apparatus power packs, oscillators, and electric fans, which gave an average noise level of 50 dB. The quiet condition was obtained by the subject wearing a pair of ear guards giving a noise level of 20 dB. The results confirm the prediction made from the theory relating arousal, performance and personality outlines in the introduction in that extroverts showed greater improvement in c.f.f. performance with an increase in auditory noise than did introverts. The introverts showed no change in performance suggesting that they were already at their optimum level of arousal for this task. Such an interpretation could account for the equivocal results of



previous experiments which have investigated individual differences or the effects of auditory noise on c.f.f. Clear differences between personality groups would only appear if the groups were well below or above their optimum levels of arousal. The same would apply to the effects of arousing factors. If the arousal of a group of subjects already in the region of the optimum level of arousal were increased, then about half would show improved performances and the rest depressed performances. However, the clear increase in performance produced by stimulant drugs is not consistent with this hypothesis. A further complication is the marked order effect found in the present study. This suggests that a learning effect operates to produce changes in performance quite independently of changes in arousal. Quite apart from these complications, if it is correct that in normal conditions subjects are close to their optimum level of arousal for c.f.f. performance, then c.f.f. performance should not be a good measure of changes in arousal, since points from the top of the inverted-*U* must give the least sensitive and the least reliable reflections of changes in arousal.

Glass, D.C., Singer, J.E. and Friedman, L.N. PSYCHIC COST OF  
1969 ADAPTION TO AN ENVIRONMENTAL STRESSOR. *J. of Personality and Soc. Psychol.*, 12(3), 200-210.

Two laboratory experiments were conducted to investigate the behavioral consequences of adaptation to repeatedly presented aversive noise. Experiment I showed that among a groups of college females, the work of adapting to unpredictable, in contrast to predictable, noise resulted in lower tolerance for frustration and in impaired performance efficiency after termination of the noise. These effects were more pronounced when the unpredictable noise was delivered at 110 dB compared to 56 dB. The behavior of the subjects in both predictable-noise conditions did not differ significantly from no-noise control subjects. Experiment II showed that the adverse post-adaptive effects following loud unpredictable noise were substantially reduced if the subject believed that he had control over the termination of the noise. The effects of cognitive factors

on post-adaptive responses to noise were discussed, and several theoretical interpretations of the results were offered.

Glucksberg, S., Karsh, R. and Monty, R.A. SEQUENTIAL  
1967 MEMORY-KEEPING TRACK PERFORMANCE AS A  
FUNCTION OF INFORMATION EXPOSURE TIME AND  
INTERSTIMULUS NOISE. *Perceptual and Motor Skills*, 24,  
651-56.

Green, D.M. and Swets, J.A. SIGNAL DETECTION THEORY AND  
1966 PSYCHOPHYSICS. Wiley, New York.

Covers decision processes in detection, sensory processes in detection as defining the ideal observer, and applications to multiple observations, frequency analysis, speech communication, and a variety of problems in perception. 100 references.

Grimaldi, J.V. SENSORY-MOTOR PERFORMANCE UNDER  
1958 VARYING NOISE CONDITIONS. *Ergonomics*, 2, 34-43.

A group of subjects performed a task in quiet and noisy environments. The noise was intermittent, within the frequency range of 75 to 9600 cycles and at sound levels of 70, 80, 90, and 100 dB. The study was experimental, but simulated an occupational situation. There was a tendency for more errors and less precision when working in the noisy environment. Response times were slower and the number of errors greater than when noise levels and frequencies were highest. The frequency range of 2400-4800 cycles was associated with the slowest response time, and the largest number of errors with 90 and 100 dB. It appears that intermittent noise may have a reducing effect on the individual's capacity for quick and precise execution of coordinated movements. The implications for safety and certain production tasks seem obvious.

Guignard, J.C. and Gillies, J.A. NOISE. *A Textbook of Aviation*  
1965 *Physiology*, 895-967.

Gulian, E. EFFECTS OF NOISE ON AROUSAL LEVEL IN  
1970 AUDITORY VIGILANCE. *Acta Psycho.*, 33, 381-393.

Hack, J.M., Lathrop, R.G. and Rutgers, U. AUDITORY  
1965 DISTRACTION AND COMPENSATORY TRACKING.  
*Perceptual and Motor Skills*, 20, 228-230.

Harmon, F.L. THE EFFECTS OF NOISE UPON CERTAIN  
PSYCHOLOGICAL AND PHYSIOLOGICAL PROCESSES.  
*Arch. Psychol.*, 147, 1-81.

Harris, C.S. THE EFFECTS OF HIGH INTENSITY NOISE ON  
1968 HUMAN PERFORMANCE. Aerospace Med. Res. Labs,  
Wright-Patterson AFB, Ohio, AD-671-116.

Harris, C.S. and Shoenberger, R.W. HUMAN PERFORMANCE AS  
1965 A FUNCTION OF CHANGES IN ACOUSTIC NOISE  
LEVELS. Acoustic Noise Levels Final Report, AD 618324.

Hickling, S. NOISE INDUCED HEARING LOSS AND POP MUSIC.  
1970 *N. Z. Med. J.*, (453), 94-96.

Hockey, G.R.J. EFFECT OF LOUD NOISE ON ATTENTIONAL  
1970 SELECTIVITY. *Quart. J. Exp. Psychol.*, 22, 28-36.

Hormann, H. and Todt, E. NOISE AND LEARNING. *J. Exp. Appl.*  
1960 *Psychol.*, 7, 422-26.

Houston, B.F. INHIBITION AND THE FACILITATING EFFECTS  
1968 OF NOISE ON INTERFERENCE TASKS. *Perceptual and*  
*Motor Skills*, 27, 947-50.

Hsia, H.J. EFFECTS OF NOISE AND DIFFICULTY LEVEL OF  
1968 INPUT INFORMATION IN AUDITORY, VISUAL AND  
AUDIOVISUAL INFORMATION PROCESSING. *Perceptual*  
*Motor Skills*, 26, 99-105.

Hummel, W.F., Turner, J.W. and Cohen, A. VIGILANCE  
1965 PERFORMANCE IN NOISE AS RELATED TO  
PERSONALITY AND NOISE TOLERANCE. Occupational  
Health Research and Training Facility, Report TR-20,  
Cincinnati, Ohio.

Ioseliani, K.K. THE EFFECT OF VIBRATION AND NOISE ON  
1967 THE MENTAL FACULTY OF MAN UNDER TIME  
STRESS. Joint Pub. Res. Serv.

Jansen, G. NOISE EFFECT DURING PHYSICAL WORK. *Intern.*  
1964 *Z. Angew. Physiol.*, 20, 233-39.

Jerison, H.J. ACTIVATION AND LONG TERM PERFORMANCE.  
1967 *Acta Psychol.*, 27, 373-389.

Is activation theory useful or necessary for the analysis of long term performance on perceptual tasks? After criticizing the theory for being too broad and nonspecific, because even contradictory results would not embarrass it, this report illustrates the problem with data on human and animal vigilance. It is concluded that activation theory in several forms may be necessary to understand different phases of vigilance performance. The questions relevant for activation theory include the probable inhibition of observing behavior when an overload is established by eliciting observations at a high rate, the temporal conditioning of levels of arousal, and motor aspects of the emission of detection-indicating responses.

Jerison, H.J. EFFECTS OF NOISE ON HUMAN PERFORMANCE.  
1959 *J. Appl. Psychol.*, 43, 96-101.

The results of three experiments relating performance changes to noise levels are reported. Noise levels used were about 80 dB representing "quiet" and 110 dB representing "noise." Changes in alertness as determined on a clock-watching task were found after one and one-half hours in noise though none were found in quiet. Time judgements—the estimation of the passage of 10-minute

intervals—were distorted by noise; subjects responded on the average of every nine minutes in quiet and every seven minutes in noise when instructed to respond at what they judged to be 10-minute intervals. A significant but complex effect of noise on a mental counting task was also found. These effects are discussed in terms of noise as a source of psychological stress.

Jerison, H.J. PERFORMANCE OF A SIMPLE VIGILANCE TASK  
1957 IN NOISE AND IN QUIET. *J. Acoust. Soc. Amer.*, 29(11),  
1163-65.

Twenty subjects, working individually, monitored a simple vigilance task, a modified "Mackworth Clock Test," for 1½ hours in noise (112.5 dB SPL) and for 1½ hours in quiet (79 dB SPL). No difference in efficiency attributable to noise level was found. This result is in conflict with previous reports from this and other laboratories which ascribed a decrement in performance on vigilance tasks to noise levels. Vigilance tasks in which performance decrements due to noise were found differed from the present task in that they required subjects to scan a series of displays in addition to maintaining a vigil over each display. It is, therefore, suggested that flexibility of attention may be affected by noise, whereas vigilance without the requirement for flexibility may be unaffected.

Jerison, H.J. PACED PERFORMANCES ON A COMPLEX  
1954 COUNTING TASK UNDER NOISE AND FATIGUE  
CONDITIONS. *Am. Psychol.*, 9, 399-400.

Jerison, H.J. and Pickett, R.M. VIGILANCE: A REVIEW AND  
1963 REEVALUATION. *Human Factors*, 5, 211-38.

Vigilance as a human factors area is concerned with the fact that man is much less capable as a detector of signals under operational conditions than would be indicated by laboratory measures of his sensory thresholds. The area, which is obviously important for the analysis of man's visual capabilities in the operation of manned space systems, is

re-examined with the help of a theoretical model that introduces a decision-theory approach to the observing response phase of the vigilance task. After a critical review of the vigilance literature, examples are presented of the application of this approach to the solution of human factors problems of the sort that might arise in manned space missions. The model is also used to suggest the kind of research that makes it easier to predict field monitoring performance from laboratory experiments.

Jerison, H.J. and Wing, S. EFFECTS OF NOISE AND FATIGUE  
1957 ON A COMPLEX VIGILANCE TASK. WADC Tech. Report  
TR-57-14.

Keenan, J.J. SOME EFFECTS OF RHYTHMIC DISTRACTION  
1968 UPON RHYTHMIC SENSORI-MOTOR PERFORMANCE. *J.*  
*Exp. Psychol.*, 77, 440-6.

Kirk, R.E. and Hecht, E. MAINTAINANCE OF VIGILANCE BY  
1963 PROGRAMMED NOISE. *Perceptual and Motor Skills*, 16,  
553-60.

This research was designed to compare the relative effect of three environmental conditions on the performance of a simple vigilance task. The vigilance task consisted of a cathode ray tube display which was monitored by 30 subjects for 2 hours. Three environmental conditions were randomly introduced while subjects monitored the display. The conditions were a constant noise of 64.5 dB, a variable noise having an average SPL of 64.5 dB, and a quiet condition of 61 dB. The results indicate that the probability of signal detection is higher for the variable noise condition than for the constant noise and quiet conditions. No difference in probability of detection was found between the latter two conditions. An explanation for the facilitating effect of sensory stimulation on vigilance is sought in terms of the alerting and general arousal effects attributed to the reticular activating system.

Kovrigin, S.D. and Mikheyev, A.P. THE EFFECT OF NOISE LEVEL  
1965 ON WORKING EFFICIENCY. Joint Publications Research  
Service, N65-28297, Washington, D. C.

Kryter, K.D. THE EFFECTS OF NOISE ON MAN. *J. Speech and*  
1950 *Hearing Disorders*, Monograph Suppl. 1.

An extensive summary of the effects of noise on man as  
known prior to 1950. A comprehensive bibliography  
accompanies each topic under discussion. No significant  
effects on performance were reported.

Laird, D.A. THE EFFECTS OF NOISE—SUMMARY OF  
1930 EXPERIMENTAL LITERATURE. *J. Acoust. Soc. Amer.*, 1,  
256-62.

LeBlanc, R. and Kirk, R.E. THE PERFORMANCE OF "LABILE"  
1961 AND "STABLE" SUBJECTS ON A SIMPLE VIGILANCE  
TASK IN QUIET AND IN NOISE. Paper read at  
Southwestern Psychological Assn., Little Rock, Ark.

Lehmann, D.W., Creswell, W.H. and Huffman, W.J. AN  
1965 INVESTIGATION OF THE EFFECTS OF VARIOUS NOISE  
LEVELS AS MEASURED BY PSYCHOLOGICAL  
PERFORMANCE AND ENERGY EXPENDITURE. *J. Sch.*  
*Health*, 35, 212-4.

The findings of the study were as follows: Students achieved  
their highest scores on mathematical computation under the  
"quiet" condition and made progressively poorer scores  
under the higher noise level conditions. The differences  
obtained under the three experimental noise levels were all  
statistically significant (20-25, 50-55, 80-85 dB). Students  
obtained significantly higher test scores on the test of reading  
comprehension under the "quiet" condition as compared to  
their scores under the experimental "loud" noise condition.  
The differences obtained on the reading comprehension  
scores under "quiet" and "normal" noise levels were not  
statistically significant. Students required more time to

complete the mathematical computation test under the loud noise condition. Students consumed more oxygen under the higher noise levels, thus revealing a higher energy expenditure. It should also be noted that the normal noise condition caused a significantly higher energy expenditure than did the quiet noise condition.

Loeb, M. and Jeantheau, G. THE INFLUENCE OF NOXIOUS ENVIRONMENTAL STIMULI ON VIGILANCE. *J. Appl. Psychol.*, 42, 47-9.

Twelve subjects in an Army troop carrier were asked to detect and respond to obscure, randomly occurring signals under each of four field conditions. In the control condition, the noise and heat levels were moderate and the vehicle was stationary. During the noise and vibration condition, the vehicle was moving, noise and vibration were considerable, and the temperature was moderate. In the heat condition, the heat was rather intense, the noise was moderate, and the vehicle was stationary. During the heat, noise, and vibration condition, the vehicle was moving, and the noise, heat, and vibration levels were rather high. Noise and vibration produced by the moving vehicle appreciably increased the median response times of the subjects. Further decrement occurred when heat was combined with noise and vibration, but the effect was relatively transitory. Heat alone had no apparent effect. Changes occurring as a function of elapsed time were not apparent.

Lukas, J.S., Peeler, D.J. and Kryter, K.D. EFFECTS OF SONIC BOOMS AND SUBSONIC JET FLYOVER NOISE ON SKELETAL MUSCLE TENSION AND A PACED TRACING TASK. *J. Acoust. Soc. Amer.*, 50(1), part 1.

Mackworth, J.F. VIGILANCE, AROUSAL AND HABITUATION. *Psychological Review*, 75, 308-22.

Decrements in performance in vigilance tasks are discussed in terms of habituation of the neural responses to the background events of the tasks. Habituation of the arousal



response leads to an increase in variance and amplitude of the spontaneous neural rhythms; this increase in neural noise may result in a decrease in sensitivity to the signal events. Habituation of the evoked responses to both signal and nonsignal events of the task produces a decrease in amplitude and increase in latency of the evoked response. This may be the cause of decreases in correct and false detections which are found in many vigilance tasks. Sensitivity may increase as the neural evoked response to the nonsignal events decreases, thus counteracting the effect of the decrease in the arousal response.

Mackworth, N.H. RESEARCHES ON THE MEASUREMENT OF  
1950 HUMAN PERFORMANCE. Her Majesty's Stationary Office,  
Medical Research Council, Special Report 268.

Martz, R. AUDITORY VIGILANCE AS AFFECTED BY SIGNAL  
1967 RATE AND INTERSIGNAL INTERVAL VARIABILITY.  
*Perceptual and Motor Skills*, 24, 195-203.

McBain, N.W. NOISE, THE AROUSAL HYPOTHESIS AND  
1961 MONOTONOUS WORK. *J. Appl. Psychol.*, 45, 309-17.

The contradictory findings concerning the effects of noise on performance may be reconciled by a dimensional analysis of the characteristics of the noise and of the task involved, and an attack upon specific dimensions, based upon a theoretical rather than a strictly empirical approach. In terms of the "arousal hypothesis," noise which is low in "intelligibility" (or distraction value for the individual) while at the same time being high in variability, should enhance performance in a monotonous task.

McCann, P.H. THE EFFECTS OF AMBIENT NOISE ON  
1969 VIGILANCE PERFORMANCE. *Human Factors*, 11(3),  
251-6.

The effects of continuous noise versus intermittent noise on subjects performing an audiovisual checking task were examined. Although there was no difference between the

effects of the two kinds of noise on total errors, intermittent noise produced a larger number of omission errors than did continuous noise. There were no differences in overall vigilance performance between male and female observers. There was a decrement in performance with time-at-work typically found in other vigilance studies.

McKenzie, R.E. THE EFFECT OF BINAURAL BEATS ON  
1961 PERFORMANCE. *J. Auditory Res.*, 1, 176-85.

A study was designed to determine the effects of binaural interaction, produced by binaural beat stimulation, upon certain performance measures. The hypothesis tested was that binaural beat stimulation would produce an interaction process in the central nervous system with resulting performance decrement. The results indicate that binaural beats do disrupt and hinder certain kinds of performance. A theoretical explanation involving disruption of the normal pattern of nervous system activity by hypersynchronous discharge is suggested as the mechanism by which certain forms of binaural stimulation, having periodic form, produce performance change. The fact that the binaural beats in this experiment were eight per second raises the possibility that the neural mechanism may be related to the normal alpha rhythm. Finally, there are indications that this neural process is not available to correct subjective assessment.

Mech, E.V. FACTORS INFLUENCING ROUTINE PERFORMANCE  
1953a UNDER NOISE. I-THE INFLUENCE OF "SET." *J. Psychol.*, 35, 283-98.

Formal instructions, or giving the subject an orientation as to what direction to work in, appears to be a significant variable in relation to routine production tasks. In order to produce differentially significant results and eliminate vacillation of performance, the major property of "Set" seems to be that they be clear-cut and orient the subject in a precise direction. Once the desired direction is produced, the evidence seems to indicate that frequent "Set" reinforcements are necessary to maintain superior

performance in the direction, at least in relation to the routine verbal addition task employed. Verbal noise, per se, of a given intensity, does not appear to have any necessary effect upon the execution of routine work tasks. This finding seems compatible with some physiological results—that subjects generally become adapted to the noise. There is no consistent difference in production when no effort is made to give subjects formal instructions with respect to the condition under which they are expected to perform better.

Mech, E.V. PERFORMANCE ON A VERBAL ADDITION TASK  
1953b RELATED TO EXPERIMENTAL "SET" AND VERBAL  
NOISE. *J. Exp. Educ.*, 22, 1-17.

Melzak, R. and Casey, K.L. SENSORY, MOTIVATIONAL AND  
1968 CENTRAL CONTROL DETERMINANTS OF PAIN, in D.A.  
Kenshalo (Ed.) *The Skin Sense*. Springfield, Illinois: Charles  
C. Thomas, Chapter 20.

Miller, H. EFFECTS OF HIGH INTENSITY NOISE ON  
1957 RETENTION. *J. Appl. Psychol.*, 41, 370-2.

Noise of the intensity and frequencies employed in this experiment (111 dB, approximately flat frequency spectrum to 600 cycles/sec.) does not significantly affect the recall of verbal material learned under controlled conditions. The recall of material learned by means of auditory stimulation is not interfered with by noise to a greater extent than the recall of material learned by visual stimulation. According to the subjective reports of subjects, the noise stimulus employed aroused minimal reactions in regard to eight psychological and somatic categories of reaction including general disturbance, irritation, distraction, nervousness, fright, nausea, pain and dizziness. The reports of the subjects centered around mild complaints of irritation, distraction and general disturbance. Subjective reports of the subjects indicated some initial disturbances due to the noise stimulus but that adaptation was quickly achieved and that, following adaptation, the noise was not perceived as a noxious stimulus.

Montague, W.E. EFFECT OF IRRELEVANT INFORMATION ON  
1965 A COMPLEX AUDITORY TASK. *J. Exp. Psychol.*, 69,  
230-6.

Morgan, J.B. THE OVERCOMING OF DISTRACTION AND  
1916 OTHER RESISTANCES. *Arch. of Psychol.*, 35.

*The effect of noises on activity.* The initial effect of noise is to retard the speed of work. After this initial retardation, there is an increase in speed. In many cases the subject exceeds the speed he had attained before the introduction of the noises. Extra effort is put forth to overcome the noises. This is shown by an increase in the pressure exerted upon the keys in reacting. This extra effort continues pretty uniformly throughout the noisy period. Articulation is used as a means of overcoming the effect of the noises. This articulation is shown by changes in breathing of the subject. In some cases this help is not used immediately after the introduction of the noises, showing that it is an adjustment that is more deliberate than the extra expenditure of energy. It is by means of these helps that the subject is able to eliminate the influence of noises from his time score and the extent of the use of these is more a measure of the effect of the noises than is the time record. *Time and energy relations.* In a test where numerical comparisons were possible it was found that energy changes are much more significant than time changes. A person tends to change the amount of energy expended to meet changing situations and to keep the time constant regardless of variations in conditions. We offer as a statement of the situation that any real or imagined change in the resistance offered to the maintenance of a set causes a change in the output in energy.

Murray, D.J. THE EFFECT OF WHITE NOISE UPON THE  
1965 RECALL OF VOCALIZED LISTS. *Canad. J. Psychol.*, 19,  
333-45.

Subjects either silently read, mouthed, whispered, soft-voiced, or loud-voiced lists of 8 consonants for immediate free recall. White noise of an intensity sufficient

to mask subject's hearing of his own soft voice (as far as possible) was present during presentation and/or recall. The results showed that when there was no noise at presentation, recall increased as vocalization activity increased; when there was noise throughout presentation and recall, loud voicing was significantly superior to whispering; when the noise was switched off for recall, loud voicing gave insignificantly inferior recall to soft voicing and whispering. The results are interpreted as being consistent with the view that when lists are vocalized, subjects try to attend particularly to the auditory feedback, but that if this is prevented, more attention is paid to the motor cue. Presentation rate was not found to play a significant role in this experiment.

O'Donnell, H.R. A PRACTICAL VIEW OF DB'S. *Audio*, 54(2), 1970 38-43.

Park, J.F. and Payne, M.C. EFFECTS OF NOISE LEVEL AND DIFFICULTY OF TASK IN PERFORMING DIVISION. *J. Applied Psychol.*, 47, 367-68.

Pascal, G.R. THE EFFECT OF DISTURBING NOISE ON THE REACTION TIME OF MENTAL DEFECTIVES. *Am. J. Mental Def.*, 577, 691-9.

A population of 22 mental defectives was trained on simple reaction time until a plateau of performance was reached. The reaction times of these subjects was then measured when a loud, disturbing noise was introduced with the "ready" signal. The overall first effect of the noise was a pronounced increase in reaction time. This increase was found to be significantly related to both mental and chronological age. A rough estimate of the subjects' abilities to adapt to a new situation was found to be related to the effects of noise on reaction time. A curve of adaptation showed an initial great reaction to noise, followed by a stage of adaptation. Some subjects showed a failure in adaptation and some a complete disruption of performance. The results are compared to Selye's findings with animals under stress.

Pepler, R.D. WARMTH, GLARE AND A BACKGROUND OF  
1960 QUIET SPEECH: A COMPARISON OF THEIR EFFECTS  
ON PERFORMANCE. *Ergonomics*, 3, 68-73.

In two experiments the effects of a high air temperature on the accuracy and manner of manual tracking were compared with those of quiet speech and of glare. In each experiment 12 subjects attempted to keep a pointer aligned with a moving target for 40 minutes in both a normal and a warm climate, with instructions to be as accurate as possible. During the middle 20 minutes of each period of work the subjects in one experiment faced the glare from a naked electric lamp, and those in the other had a quietly spoken narrative relayed to them. All three conditions reduced accuracy of alignment, but warmth affected the manner of tracking differently from quiet speech and glare. With the two latter conditions movements of the pointer were decreased in number, *i.e.*, errors of alignment were corrected less frequently. At a high air temperature the number of movements of the pointer increased, *i.e.*, corrections were more frequent than usual. It was concluded that glare and a background of speech interfered with perception but that warmth affected chiefly accuracy of movement.

Pettitt, L.A. THE INFLUENCE OF TEST LOCATION AND  
1958 ACCOMPANYING SOUND IN FLAVOR PREFERENCE  
TESTING OF TOMATO JUICE. *Food Tech.*, 12, 55-7.

Plutchik, R. EFFECT OF HIGH INTENSITY INTERMITTENT  
1961 SOUND ON COMPENSATORY TRACKING AND  
MIRROR TRACING. *Perceptual Motor Skills*, 12, 187-94.

Six male subjects were required to work at two tasks, mirror-tracing a star pattern, and compensatory tracking of an "horizon line" moving up and down on the screen of an oscilloscope, driven by a sinusoidal input at 24 cycles per minute. At certain times a high intensity intermittent tone was introduced, at three pulses per second, at a frequency of 1000 or 2500 cps, and at an intensity level

of 105 to 122 dB depending on the subject. These conditions were chosen on the basis of a previous experimental study of auditory pain thresholds. The major findings were as follows: The high intensity intermittent sound had no effect on compensatory tracking performance; it also had no effect on total time taken to complete the mirror-tracing task. There was a significant increase in variability of error time on the mirror tracing task. An interpretation of this was suggested in terms of the relative complexity of the tasks and in terms of task requirements. Several implications were drawn.

Plutchik, R. THE EFFECTS OF HIGH INTENSITY  
1959 INTERMITTENT SOUND ON PERFORMANCE, FEELING  
AND PHYSIOLOGY. *Psychological Bulletin*, 56, 133-51.

This review has attempted to summarize and integrate a number of articles dealing with the effects of loud and intermittent sounds on human behavior, feeling and physiology. Most of these studies have been published since 1950 when the last comprehensive review was written. Some of the more recent experiments demonstrate effects of very loud sounds on certain kinds of complex behavior, particularly "clock-watching" and time estimation, with the possibility implied that the decrement in performance may depend on the level of the sound as well as on its intermittency. With regard to the effects of high intensity or intermittent sound on feeling, the literature is almost unanimous: High intensity noise, even when it may have no effect on performance will generally produce symptoms of discomfort, irritation, and distraction, although there is little known about the relative annoyance value of different kinds and levels of intermittency. Certain unique subjective characteristics of repetitive sounds are described, relating to the effects of various rates of repetition on fusion, estimation of pulse frequency, tonal character, threshold and loudness. The greatest effects are usually obtained at repetition rates between 5 and 10 pulses per second, a frequency range which more or less coincides with the alpha rhythm of the brain. With regard to the effects of loud or intermittent sounds

on physiology, changes in blood pressure, gastric secretion, pulse rate, palmar sweating, respiration, muscle tension, the electro-encephalogram, and blood oxygen saturation have been reported in various studies. Some theoretical concepts are presented which postulate effects of auditory intermittency parallel to those of visual flicker. In general, the need for more research on the effects of intermittent sounds of various frequencies, repetition rates, and intensities is evident from this review.

Pollack, I. and Knaff, P.R. MAINTAINANCE OF ALERTNESS BY  
1958 A LOUD AUDITORY SIGNAL. *J. Acoust. Soc. Amer.*, 30,  
1013-16.

An extremely serious operational problem is the maintainance of a high level of visual target detection performance during long periods of watch. Will a loud auditory signal aid in the maintenance of a high performance level under these conditions? Apparently, it will. When the failure to detect a target was coupled with the occurrence of the blast of a truck horn, average visual target detection percentages increased substantially, especially for the less proficient observers.

Poulton, E.C. ON INCREASING THE SENSITIVITY OF  
1965 MEASURES OF PERFORMANCE. *Ergonomics*, 8, 69-76.

This paper illustrates some of the methods which have been used to increase the sensitivity of measures of performance: adjusting the difficulty of the task; saturating the man's channel capacity by giving him an additional task to perform; using an unfamiliar task; measuring variability instead of mean performance; selecting specific events on which to make measurements; examining component rather than overall measures; and channelling two dimensions of variability into one. Finally it raises a methodological difficulty in comparing the results of performance tests which may differ in sensitivity.



Poulton, E.C. THE OPTIMAL PERCEPTUAL LOAD IN A PACED  
1960 AUDITORY TASK OF INSPECTION. *Brit. J. Psychology*,  
51, 127-39.

Raab, D.H. and Grossberg, M. REACTION TIME TO CHANGES  
1965 IN THE INTENSITY OF WHITE NOISE. *J. Exp.*  
*Psychology*, 69, 609-12.

Samuel, W.M.S. NOISE AND THE SHIFTING OF ATTENTION.  
*Quart. J. Exp. Psychol.*, 16, 264-67.

Sanders, A.F. THE INFLUENCE OF NOISE ON TWO  
1961 DISCRIMINATION TASKS. *Ergonomics*, 4, 253-58.

Recent research has revealed that noise effects on work become apparent in an increasing irregularity of reaction times instead of in a general decrease in the total number of reactions. This paper is concerned with the measurement of the degree of irregularity in two paper-and-pencil tasks. Both tests were performed twice on different days for half-an-hour each. The experiment was designed to compare two different noise conditions: in one the noise changed randomly about an average level of 75 dB., in the other it was steady at 70 dB. The number of reactions in every minute was scored. To reach conclusions from the scores about the degree of regularity of the reaction times, a measure of the variance of the scores was used. Since there appeared a linear trend of score with time, it was decided to calculate the variance of the differences of score between successive minutes rather than of the scores themselves. Two variances were calculated for each day's work at each task, one over the first fourteen, and one over the last fourteen differences. The ratio of the variances (variance quotient) was taken as an indication of the change of irregularity as performance proceeded. The results showed that in one task the variance quotient was significantly larger under conditions of varying rather than steady noise. In the other task the same trend appeared in the second day's session but not in the first. The results favor Broadbent's hypothesis

that unpredictable noise affects performance more than does monotonous noise.

Shoenberger, R.W. and Harris, C.S. HUMAN PERFORMANCE AS  
1965 A FUNCTION OF CHANGES IN ACOUSTIC NOISE  
LEVELS. *J. Engr. Psychol.*, 4(4), 108-19.

Slater, B.R. EFFECTS OF NOISE ON PUPIL PERFORMANCE. *J.*  
1968 *of Educational Psychology*, 59, 239-43.

Two hundred sixty-three 7th grade public school children were tested to determine whether quiet (45-55 dB.), average (55-70 dB.), and noisy (75-90 dB.) classroom and experimental conditions had a relationship to written task performance of relatively short duration. It was hypothesized that subjects would perform better under average and noisy conditions and that boys would be more detrimentally affected by noise than girls. Noise typical of that used in schools and white noise were both used. Means and standard deviations were compared across the conditions used and analyses of variance were performed on the data. No noise effect, either detrimental or facilitating, was demonstrated on speed or on accuracy of performance. Subjects' perceptions of the effects of noise and measured anxiety had little relationship to actual performance.

Smith, K.R. INTERMITTENT LOUD NOISE AND MENTAL  
1951 PERFORMANCE. *Science*, 114, 132-33.

It has been found that the effect upon short-term mental performance of bursts of intense noise is to increase the quantity and decrease the quality of response, but that these effects are of such magnitude as to suggest that they are practically negligible. It may be that the allegedly malignant effects of extraneous noise are to be found primarily in terms of depreciation in sustained performance, or of interference with functions other than adequate output.

Stevens, S.S. THE EFFECT OF AIRPLANE NOISE ON HUMAN  
1946 EFFICIENCY. (abstract of presentation), *American Psychologist*, 1, 283.

Steuky, K. and Eysenck, H.J. PURSUIT ROTER PERFORMANCE  
1965 AS A FUNCTION OF DIFFERENT DEGREES OF  
DISTRACTION. *Life Sciences*, 4, 889-97.

Swets, J.A. SIGNAL DETECTION AND RECOGNITION BY  
1964 HUMAN OBSERVERS: CONTEMPORARY READINGS.  
New York: Wiley.

A collection of 30 papers on signal detection theory.

Teichner, E.A., Arces, E. and Reilly, R. NOISE AND HUMAN PER-  
1963 FORMANCE, A PSYCHOPHYSIOLOGICAL APPROACH.  
*Ergonomics*, 6(1), 83-97.

A theoretical approach is developed for the study of the effects of noise on human performance which takes into account the psychological factors of distraction and habituation and the physiological factors of auditory adaption and bodily arousal. Two experiments designed to test theoretical predictions suggested that the approach is reasonable. Distraction studied in terms of changes in ambient noise levels was found to be a function of the amount of change. When adaption of the ear is controlled by use of on-off sound sequences, ignoring distraction, performance is directly related to the on-off ratio early in exposure and inversely related to the ratio later in exposure. At all sound ratios performance in noise is better than in quiet. When distraction is taken into account, these results are influenced by the differences in rate and amount of adaptation to loudness and rate of habituation to distraction so that at any given time performance may seem to be decreased, increased or unaffected.

Treisman, A.M. REPLY TO COMMENTS ON "SELECTIVE  
1967 LISTENING: PERCEPTION OR RESPONSE." *Quart. J.  
Experimental Psychology*, 19, 364-67.

Vaughan, H.G. Jr. and Ritter, W. THE SOURCES OF AUDITORY  
1970 EVOKED RESPONSES RECODED FROM THE HUMAN  
SCALP. *Electroenceph. Clin. Neurophysiol.*, 28(4), 360-67.

Viteles, M.S. and Smith, K.R. AN EXPERIMENTAL  
1946 INVESTIGATION OF THE EFFECT OF CHANGE IN  
ATMOSPHERIC CONDITIONS AND NOISE UPON  
PERFORMANCE. *Trans. Amer. Soc. Heat. Vent. Engs.*, 52,  
167-82.

Vlasak, M. EFFECTS OF STARTLE STIMULI ON  
1969 PERFORMANCE. *Aerosp. Med.*, 40, 124.

Warner, H.D. EFFECTS OF INTERMITTENT NOISE ON HUMAN  
1969 TARGET DETECTION. *Human Factors*, 11(3), 245-49.

The purpose of the present investigation was to examine the effects of intermittent noise on target detection performance. Specifically, the present study was designed to test whether the effects of noise presented at a 70 percent on-off, "neutral" ratio are independent of the noise intensity level. Four levels of noise were used: no noise, and 80, 90, and 100 dB. The results revealed that detection time was not significantly affected by noise level. The total number of errors recorded for each noise condition showed that, in general, as intensity level increased, the total number of errors decreased. These findings are related to the concept of "flexibility of attention."

Watkins, W.A. EFFECT OF CERTAIN NOISES UPON DETECTION  
1964 OF VISUAL SIGNALS. *J. Exp. Psychol.*, 67, 72-5.

The influence of auditory noise stimulation upon detection of a visual signal was investigated by manipulation of two variables: noise type and mode of presentation. Six trained subjects each performed 1200 forced-choice trials in which they were required to select one of four temporal observation intervals as that in which the visual signal occurred. It was found that detection performance was substantially better when noise was presented only during observation intervals than when it was continuously present. Steady white noise and auditory flutter, both at 75 dB. SPL, were equally effective in the apparent facilitation of visual detection.

Weston, H.C. and Adams, S. TWO STUDIES OF THE  
1932 PSYCHOLOGICAL EFFECTS OF NOISE. Rep. Industr.  
Health Res. Board, Lond. No. 65, Industrial Health Research  
Board, Report No. 65.

Weston, H.C. and Adams, S. THE PERFORMANCE OF WEAVERS  
1935 UNDER VARYING CONDITIONS OF NOISE. Industrial  
Health Research Board, Report No. 70, HD 7695, A3,  
London.

Wilbanks, W.A., Webb, W.B. and Tolhurst, G.C. A STUDY OF IN-  
1956 TELLECTUAL ACTIVITY IN A NOISY ENVIRONMENT.  
Naval School of Aviation Medicine, Pensacola, Florida. Re-  
port No. NAVMED-NM-001-104-100-1, AD 620-263.

Wilkinson, R.T. CHANGES IN PERFORMANCES DUE TO  
1964 ENVIRONMENTAL FACTORS. Symposium on medical  
aspects of stress in the military climate, Walter Reed Medical  
Center, Washington, D.C., 127-35.

Wilkinson, R.T. INTERACTION OF NOISE WITH KNOWLEDGE  
1963 OF RESULTS AND SLEEP DEPRIVATION. *J. Experi.*  
*Psychology*, 66, 332-7.

One hundred dB. white noise impairs performance of thirty-minute choice serial reaction: Does this effect vary under (Experiment I) 32-hour sleep deprivation (SD) and (Experiment II) increased knowledge of results (KR)? Twelve enlisted men in each experiment carried out the four condition combinations in balanced order of presentation. The effect of noise was increased by KR, reduced by SD and greater among subjects with previous practise on the test. Conclusions are: (a) Noise impairs performance as incentive is high and as the task loses novelty through practise. (b) Noise and SD produce different types of "fatigue" which may oppose each other's action. With SD arousal may be too low (especially with no KR); with noise it may be too high (especially with KR).

Wisner, A. and Tarriere, C. THE EFFECTS OF NOISE ON  
1964 VIGILANCE AS RELATED TO ITS PHYSICAL  
CHARACTERISTICS. *Acoustica*, 14, 216.

The effects of noises on behavior during a long period can be classified as a function of their significance and their physical characteristics. Among the non-significant noises, those which are short and unexpected determine an immediate disturbance followed by an improvement of vigilance for a certain lapse of time. In a monotonous situation, continuous noises can sometimes slightly improve the results during an initial period soon followed by a markedly reduced attention. This double effect is much more marked when the noise is intense and shrill. When noises constantly change in their intensity and in their spectral composition constituting the working environment, the degrading effect is still earlier and more marked than in the case of monotonous noise. Music seems a more favorable condition for good vigilance and to be superior to the condition created by monotonous noise. Speech gives very different results according to the subject's knowledge of the job. One finds these opposite effects of noise (stimulation and distraction) in the analysis of the investigations regarding music in industry. The working environment and in particular the noise environment appear to influence the watching efficiency of the operator. The results obtained in the factories sometimes seem contradictory. A classification of noises probably allows one to make a more exact appreciation of the phenomena. We recall in the first instance the data from the literature concerning non-significant noises, then we describe the results that we have been able to obtain with significant noises, and finally we try to extract some useful recommendations for working conditions.

Woodhead, M. PERFORMING A VISUAL TASK IN THE VICINITY  
1969 OF REPRODUCED SONIC BANGS. *J. Sound Vib.*, 9(1),  
121-25.

Woodhead, M. AN EFFECT OF NOISE ON THE DISTRIBUTION  
1966 OF ATTENTION. *J. Applied Psychology*, 50, 296-99.

Woodhead, M.M. SEARCHING A VISUAL DISPLAY IN  
1964a INTERMITTENT NOISE. *J. Sound Vib.*, 1(2), 157-61.

An experiment was carried out to investigate the possible effects of auditory distractions when the visual task was to search a display, in which random numbers were presented at the rate of five per second. A circle round any number was an instruction to the observer to cross off any repetitions of that number, changing to a new one whenever another circle appeared. There were three auditory conditions: (a) brief bursts of noise at 110 dB. SPL, (b) bursts at 70 dB., (c) always quiet. Conditions (b) and (c) were alternative experimental controls. It was found that the number of errors in the whole of a fifteen minute search did not differ between the three conditions, but searching was less efficient in the half-minutes following the bursts at 110 dB. compared with the same periods in either control. The errors which occurred more often in loud noise were of a particular type: failure to notice the circles. It is suggested that noise increased the observer's general level of activity, enlarging differences which the need to monitor two unequally occurring features of the display, circles and numbers, had already established.

Woodhead, M.M. THE EFFECT OF BURSTS OF NOISE ON AN  
1964b ARITHMETIC TASK. *Amer. J. Psychology*, 77, 627-33.

Bursts of 100 dB. noise were found to affect performance in arithmetic. In each of forty problems the subjects were required to memorize a six-digit number from a visual display and then to subtract from it a visible four-digit number. In comparison with quiet conditions, the occurrence of a brief noise while the numbers were being learned produced a tendency to get the subsequent calculation wrong. When the noise occurred during the calculating period the rate of work increased throughout the session from a rather slow start. Thus the effects of a burst of noise depend upon its relationship with different parts of the task. An occurrence during perception and learning does not have the same effect as one during calculation.

Woodhead, M.M. THE EFFECT OF BRIEF LOUD NOISE ON  
1959 DECISION-MAKING. *Journal of the Acoustical Society of America*, 31, 1329-31.

An experiment was designed to investigate whether irrelevant loud bursts of low-frequency noise affected decision-making unfavorably. Analysis of the results revealed a significant decrement in performance due to the noise distraction. Scores for the whole of a 4-minute test were unimpaired because only those responses immediately following the noise were affected. A second experiment demonstrated that effects were related to intensity.

Woodhead, M.M. THE EFFECTS OF BURSTS OF LOUD NOISE  
1958 ON A CONTINUOUS VISUAL TASK. *British Journal of Industrial Medicine*, 15, 120-25.

Wyon, D.P. STUDIES OF CHILDREN UNDER IMPOSED NOISE  
1970 AND HEAT STRESS. *Ergonomics*, 13(5), 598-612.

An assessment is made of moderate stress as a field of study in itself, in which principles governing the choice of criteria of stress and strain are reviewed. The most important parameters of moderate stress research are identified and placed in the context of an empirical scheme, with reference to which their interpretation and relevance are discussed. Studies by the author of children under imposed heat stress are used to illustrate the scheme and are interpreted in terms of arousal and effort. An approach to the study of noise in the moderate stress region is suggested, in which measures based on sound pressure level are unlikely to have much relevance. This view is supported by preliminary results from a study of children under intermittent low-level noise.



## NOISE

### Section (c): Surveys of Responses to Noise

**Beranek, L.L. REVISED CRITERIA FOR NOISE IN BUILDINGS.**  
1957 *Noise Control*, 3, 19-27.

**Beranek, L.L. CRITERIA FOR OFFICE QUIETING BASED ON**  
1956 **QUESTIONNAIRE RATING STUDIES.** *Journal Acoustic Society of America*, 28(5), 833-52.

In order to discover what are the maximum noise levels that office personnel find acceptable and what their reactions are to noisy offices, a survey was carried out at a large air base. A questionnaire composed of fifteen rating scales was administered to 190 people scattered over seventeen different locations on the base. The rating scales allowed the workers to assess such things as the "noisiness" of their environment and to appraise the effect of noise on various aspects of their work, such as their ability to converse or to use the telephone.

**Borsky, P. N. EFFECTS OF NOISE ON COMMUNITY BEHAVIOR.**  
1969 Conference on Noise as a Public Health Hazard, American Speech and Hearing Association, 187-92.

**Borsky, P.N. COMMUNITY REACTIONS TO AIR FORCE NOISE.**  
1961 **PART I-BASIC CONCEPTS AND PRELIMINARY METHODOLOGY; PART II DATA ON COMMUNITY STUDIES AND THEIR INTERPRETATION.** Biomedical

Lab, Aerospace Medical Lab, Wright Air Dev. Division WADD  
Technical Report 60-689 (I & II), AD 267-052(I),  
267-057(II).

*Part I--Basic Concepts and Preliminary Methodology.* A comprehensive conceptual scheme to describe the annoyance and complaint processes involved in community reactions to jet aircraft noise and related operations has been developed. This broad theoretical framework is based on a more detailed evaluation of a NACA study, a series of intensive personal interviews with New York City and Hanscom Air Force Base residents, and discussions with technical personnel concerned with acoustics, public relations, jet manufacturing, and flight operations. The theoretical scheme deals with broad aspects of the problem: the objective physical characteristics of jet stimuli and related residential disturbances, the intervening sociopsychological variables affecting individual perception, feelings of annoyance, the additional interacting factors modifying individual expression of such feelings and the overall community considerations determining the scope of community action. A standard personal interview questionnaire has also been developed and pretested for possible use in validating the conceptual scheme and deriving precise statistical relationships among the many variables.

*Part II--Data on Community Studies and Their Interpretation* To determine preliminary relationships between variations in acoustic situations and disturbance, annoyance and complaint potentials, personal interviews were held with almost 2500 residents at different air bases. The detailed acoustic conditions at three of these bases were measured. From these studies, the instruments and procedures for assessing neighborhood reactions have been fully developed, pretested, and validated. The data has provided valuable findings and the development of prototype statistical models for estimating neighborhood disturbance, annoyance, and complaint readiness. Community reactions are directly related to the intensity of the noise levels. A person is more disturbed, annoyed, and ready to complain if he is fearful of crashes and feels the air base is less important to local welfare and is less satisfied with general living conditions in his area, is more sensitive to noise of

cars and trucks, and has less experience with flying. Time by itself has been proved no automatic cure of the annoyance problem. People who have lived near air bases longer are even more bothered by the airplane noise.

Borsky, P.N. SOME OF THE HUMAN FACTORS UNDERLYING  
1958 COMMUNITY REACTIONS TO AIR FORCE NOISE. Paper presented at the Sixth Annual Meeting, Armed Forces-National Research Council Comm. on Hearing and Bioacoustics, Washington, D.C.

Cederloff, R., Jonsson, E. and Sorenson, S. ON THE INFLUENCE  
1967 OF ATTITUDES TO THE SOURCE OF ANNOYANCE REACTIONS TO NOISE: A FIELD EXPERIMENT. *Nord. Hyg. T.*, 48, 46-59.

Embleton, T.W., Dagg, I.R. and Thiessen, G.J. EFFECT OF  
1959 ENVIRONMENT ON NOISE CRITERIA. *Noise Control*, 5(6), 37-40.

Fenichel, H. SOUND AS A FACTOR IN URBAN AESTHETICS.  
1955 Master of City Planning Thesis, Berkeley.

Fog, H., Jonsson, E., Kahland, A., Nilsson, A. and Sorenson, S.  
1968 DISTURBANCE FROM TRAFFIC NOISE IN RESIDENTIAL AREAS. *Build International*, 1, 55-7.

The results show that exposure can quite safely be measured in dB(A) and can be expressed as a mean energy value. However, the importance of speed shows that a scale of exposure that takes into consideration fluctuations in sound would give an increased possibility of predicting the risk of disturbance. The very obvious importance of location variables regarding variation in disturbance can for the most part be explained as merely an effect of the exposure.

Franken, P.A. and Jones, G. ON RESPONSE TO COMMUNITY  
1969 NOISE. *Applied Acoustics*, 2, 241-46.

While high-level discrete noise events, such as aircraft flyovers, seem to be perceived as a sum of total energy, the

low-level, rapid-event noise patterns that characterize ground transportation and other community noise seem to be perceived as a difference between these patterns and their ambient counterparts. Response seems primarily a function of noise level in the case of aircraft flyovers, but not in the case of other community noise, where non-physical factors seem to play a large part in shaping aversive reactions. Control of urban noise means taking account of ambient noise and of non-physical antecedents to aversive reactions, and probably involves noise zoning.

Galloway, W.J. and von Gierke, H.E. INDIVIDUAL AND  
1966 COMMUNITY REACTION TO AIRCRAFT NOISE:  
PRESENT STATUS AND STANDARDIZATION OF  
EFFORTS. London Noise Conference.

Griffiths, I.D. A NOTE ON THE TRAFFIC NOISE INDEX AND  
1968 THE EQUIVALENT SOUND LEVEL. *Journal of Sound and  
Vibration*, 8(2), 298-300.

Recent continental work has suggested the use of a complex method, the "equivalent sound level," in the physical assessment of noise-nuisance. Work at the Building Research Station on traffic noise has led to the development of a simpler index closely related to residents' expressed dissatisfaction with their traffic noise conditions. The paper compares the two methods as predictors of dissatisfaction.

Griffiths, I.D. and Langdon, F.J. SUBJECTIVE RESPONSE TO  
1968 ROAD TRAFFIC NOISE. *Journal of Sound and Vibration*,  
8(1), 16-32.

A study consisting of acoustic measurements at fourteen sites in the London area and 1200 interviews dealing with the effects of the noise conditions prevailing at each of these sites has been carried out with the object of developing acceptability criteria for traffic noise from roads in residential areas. Dissatisfaction with the noise conditions, as expressed by residents at each of these sites, was related to sound levels in such a way that it was possible to predict

the median level of dissatisfaction at each site by the use of a measure taking into account the mean sound levels exceeded for 90 and 10% of the sampling periods throughout a whole day, which it is proposed to call the Traffic Noise Index (TNI). Predictions made on the basis of either 10 or 90% levels alone were considerably less accurate than those made on the basis of the combined measure. Individual dissatisfaction scores correlated poorly with physical measures. This finding is believed to be the result of wide individual differences in susceptibility to and experience of noise, as well as in patterns of living likely to be disturbed by noise. Attempts to allow for these factors were unsuccessful. Disturbance of various activities was shown to be related to noise levels and the increasing extent of this effect with worsening of noise conditions was used to validate the scale of dissatisfaction.

Hilton, D.A., Huckel, V., Steiner, R. and Maglieri, D.J. SONIC  
1964 BOOM EXPOSURES DURING FAA COMMUNITY  
RESPONSE STUDIES OVER A SIX MONTH PERIOD IN  
THE OKLAHOMA CITY AREA. NASA TN D-2539.

Jonsson, E. ON THE INFLUENCE OF ATTITUDES TO THE  
1967 SOURCE ON ANNOYANCE REACTIONS TO NOISE: AN  
EXPERIMENTAL STUDY. *Nord. Hyg. T.*, 48, 35-45.

Kryter, K.D. SONIC BOOM—RESULTS OF LABORATORY AND  
1969 FIELD STUDIES. Noise as a Public Health Hazard, American  
Speech and Hearing Association, 208-227.

Langdon, F.J. STUDY OF ANNOYANCE CAUSED BY NOISE IN  
1965 AUTOMATIC DATA PROCESSING OFFICES. *Building Sci.*,  
1, 69-78.

Noise levels were measured in three types of office rooms and occupants' assessments recorded on a questionnaire containing a seven-point rating scale together with comparative questions relating noise to other environmental variables. Noise was found to be the most important single source of annoyance and noise levels were rated too high

to be regarded as satisfactory in more than half of the rooms studied. Degree of annoyance was found to be related to noise level, with significant differences between occupational grades leading to a concept of noise level expectancies for different occupations. The possibilities of damage to hearing and interference with speech communication are considered and maximum noise levels for both speech conversation and comfort are suggested. The problem of noise control in offices is discussed and the results of an experiment reported together with general suggestions for the treatment of mechanized offices.

Langdon, F.J. and Scholes, W.E. THE TRAFFIC NOISE INDEX:  
1968 METHOD OF CONTROLLING NOISE NUISANCE. *The Architects Journal*.

McKennell, A.C. AIRCRAFT NOISE ANNOYANCE AROUND  
1963 LONDON (HEATHROW) AIRPORT. Central Office of Information, *The Social Survey*, Great Britain.

McKennell, A.C. and Hunt, E.A. NOISE ANNOYANCE IN  
1966 CENTRAL LONDON. Central Office of Information, *The Social Survey SS.332*, Great Britain.

Nixon, C.W. SONIC BOOM—A COMMUNITY STUDY. Conference  
1969 on Noise as a Public Health Hazard, American Speech and Hearing Association, 238-55.

Peak overpressure level, the unit typically used to describe sonic boom intensity, cannot be expected to describe adequately sonic boom exposures in terms of community reaction. In the laboratory, judgments of loudness or acceptability may be reliably related to descriptions of the stimulus which may involve appropriate characteristics of the pressure-time history of the boom. In time, advances in technology will surely allow sonic boom exposure criteria to be formulated. However, for our current understanding of the community situation, it is clear that the sociopsychological environments and experiences of the residents may exert more influence of response behavior than

do variations in the stimulus exposure. A level of acceptability of sonic boom exposure in the community was not established by the study. Degrees of acceptance and various factors which influenced them were measured under the various conditions which transpired. The significance of this information must be judged by the individual (or agency) users and the manner in which they wish to apply the information. Conclusions are not necessarily in order, but there is considerable basis for interpretation. The nature of the problem in the community is very complicated and there may be room for some controversy. Nevertheless, the program represents a relatively successful endeavor in a new field of human experience.

Nixon, C.W. HUMAN RESPONSES TO SONIC BOOM. *Aerospace Medicine*, 36, 399-405.

Nixon, C.W. and Borsky, P.N. EFFECTS OF SONIC BOOM ON PEOPLE: ST. LOUIS, MISSOURI, 1961-1962. *Journal Acoustic Society of America*, 39, Supplement, S51-S58.

Nixon, C.W. and Hubbard, H.H. RESULTS OF USAF-NASA-FAA FLIGHT PROGRAM TO STUDY COMMUNITY RESPONSES TO SONIC BOOMS IN THE GREATER ST. LOUIS AREA. NASA Tech. Note no. D-2705.

NOISE: FINAL REPORT OF THE COMMITTEE ON THE PROBLEM OF NOISE. Her Majesty's Stationary Office, London.

Parrack, H.O. COMMUNITY REACTION TO NOISE. In C.M. Harris, 1957 *Handbook of Noise Control*, McGraw-Hill, Ch. 36.

Rathe, E.J. and Muheim, J. EVALUATION METHODS FOR TOTAL NOISE EXPOSURE. *Journal of Sound and Vibration*, 8(1), 106-15.

The concept of total noise exposure uses the duration of a noise signal as well as its level to define a comprehensive

numerical index. Four practical evaluation methods are described. A comparison of the results obtained with samples of recorded noise shows that time-saving statistical methods can be applied.

**Robinson, D.W. THE CONCEPT OF NOISE POLLUTION LEVEL.**  
1969 National Physical Laboratory, Aerodynamics Division, Great Britain, Aero Report, 38.

Different indices are in current use for expressing the nuisance value of successions of noises, according to the type of noise. A single index, termed "noise pollution level," accommodates the experimental results of surveys of aircraft and of motor vehicle noise. The same formula satisfactorily explains the results of laboratory tests in which noise intensity is traded against duration to maintain equal impressions of objectionableness. The index is based on two terms, one representing the equivalent continuous noise level on the energy basis, and the other representing the augmentation of annoyance when fluctuations of noise level occur. Various practical simplifications of the formula are discussed.

**Scholes, W.E. TRAFFIC NOISE CRITERIA.** Current paper 38/39,  
1969 Building Research Station, Great Britain.

Traffic noise needs to be described in physical terms such that measurements or predictions of noise exposure in these units are effectively measurements or predictions of nuisance. Such units are developed by the means of social surveys, and typical current proposals: Wilson Proposals, Traffic Noise Index, and Mean Energy Level. The Wilson Proposals fail the requirements of a physical unit intended to be the basis of traffic noise control because of the lack of demonstrated correlation of noise levels with nuisance. Both Traffic Noise Index and Mean Energy Level have been shown to correlate well with nuisance but nevertheless, the formulations of these two units are, in some respects, conflicting. The development and the relative merits of the two units are discussed, and the direction of further research into traffic noise is outlined.



Stevens, K.N., Rosenblith, W.A. and Bolt, R.H. A COMMUNITY'S  
1959 REACTION TO NOISE: CAN IT BE FORECAST? *Noise  
Control*, 1(1), 163-71.

U.S.P.H.S. NOISE IN HOSPITALS—AN ACCOUSTICAL STUDY  
1963 OF NOISE AFFECTING THE PATIENT. U.S. Public Health  
Service, Division of Hospital and Medical Facilities,  
930-D-11.

Webb, D.R.B. and Warren, C.H.E. AN INVESTIGATION OF THE  
1966 EFFECTS OF BANGS ON THE SUBJECTIVE REACTION  
OF A COMMUNITY. Royal Aircraft Est. Tech. Report No.  
66072.

## Chapter VIII

### LIGHT

This chapter surveys in section (a) the proper quantity and distribution of light ("Light Calculations"); in section (b) the control of glare; and in section (c) predictions regarding the performance of lighting installations ("Responses to Lighting"). The main reference for engineering design and calculations is the *Illuminating Engineering Society Handbook* (New York, IES, 1972), edited by John Kaufman. The new fifth edition is much preferable to the fourth edition, since many revisions have been made. More recent technical information can be found in the *Journal of the Illuminating Engineering Society*.

Growth has been slow in our ability to understand human requirements for lighting and in our ability to predict the performance of a lighting installation with respect to these requirements. The work of Blackwell on understanding the strong effects of veiling glare on light required for ordinary visual tasks represents one of the main advances in the 1960s and early 1970s, with parallel development of computer programs capable of predicting the amount and effect of veiling glare. Recent editions of the IES journal should be consulted on this question, since the material was received too late for inclusion.

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## Chapter IX

### THERMAL ENVIRONMENT

The references in this chapter relate to human comfort under conditions of varying temperature, humidity, air motion and radiant heat transfer. Much of the useful information on the subject is available through the American Society of Heating, Refrigerating and Air Conditioning Engineers, in their *Fundamentals Handbook* (New York, ASHRAE, 1972). New information is published twice a year in their bulletin, *Transactions*, and in the *ASHRAE Journal*. Research is currently being done at Army laboratories in Massachusetts and at the ASHRAE laboratories in Kansas. As yet, very little work has been done to verify the field applicability of laboratory data. One recent book of interest of Givoni's *Man, Climate and Architecture* (Amsterdam, Elsevier, 1969), in which a complete index of thermal stress is developed and compared to other indices. Aside from a recent increase in laboratory activity, most of the work on thermal comfort was done in the 1920s and 1930s, with books on thermal comfort mostly published before 1955. All relevant data are well covered in the ASHRAE *Fundamentals*. New questions raised by problems of well-controlled environments in modern office buildings will no doubt lead to more research over the next decade, especially as the need for minimizing energy consumption becomes increasingly critical.

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